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THE NEW REMOTE SOLAR OBSERVATORY AT GENERAL BERTHELOT

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Abstract. In this article we present the new Solar Observatory of the Astronomical Institute of the Romanian Academy, installed at an altitude of 400 meters, in a more isolated area but close to the village of General Berthelot in Hunedoara county. Due to the much better climate and the less polluted area, the solar data acquired with the new instruments of the Berthelot Solar Observatory will continue and complete the solar data catalog of the Bucharest Solar Observatory.

Key words: Solar Observatory, telescope, solar data.

1. INTRODUCTION

The Bucharest Solar Station was inaugurated in 1958, with the construction of the solar dome and the acquisition of Carl Zeiss telescopes dedicated to the study of solar activity.

The inauguration of these facilities took place in a period when Bucharest city was relatively non-urbanized and pollution (dust and smoke), as well as atmospheric turbulence generated by roads and buildings, had low impact on solar astronomical observations.

The first solar instrument installed in the dome built under the patronage of the Romanian Academy, was the Carl Zeiss Jena refractor, 130/1950 mm (bought in 1957). Photographical observations of the photosphere were obtained for the relative number of sunspots, their coordinates and their time evolution, which establish the observational database for further analysis (for example the determination of area of sunspot groups and their behavior). In 1958, the Solar Observatory was equipped with a new Carl Zeiss Jena refractor 110/1650 mm used for patrol chromospheric observations (Dumitrache *et al.*, 2016).

Over time, these instruments were modernized with new equipment that allowed the observatory to keep up with other terrestrial observatories, but the rapid urbanization of Bucharest became a significant problem and it was necessary to use a new site, far from the degrading factors the quality of observations.

The Berthelot Observatory (Figure 1-left) is located near the village of General Berthelot in Hunedoara county, in the Haţeg depression, at an altitude of 400 meters, a location owned by the Romanian Academy and its infrastructure started in November 2018 (Birlan *et al.*, 2021) with the installation of the first 3 meter dome, intended for night observations. This was followed by the installation of a all-sky dome, also of 3 meters, and then of a third slit dome, of 4 meters, both installed in 2023, used for night observations (ScopeDome.com, 2023, 2011). The Solar Observatory Berthelot, was constructed to complete the range of solar observations carried out within the Astronomical Institute of the Romanian Academy in Bucharest.

The area has little light pollution and is surrounded on three sides by forest, providing good astro-climatic conditions, allowing for excellent solar observations.

Fig. 1 – The Berthelot Observatory (left). The solar dome (right).

The solar observation dome (Figure 1-right) was handed over to the solar team in 2023, to develop a complete facility for solar observations much better than those made at the Solar Observatory in Bucharest, due to the astro-climatic conditions and the equipment used. It is intended to be operational throughout the day through remote use.

2. SELECTION OF EQUIPMENT

The entire system (Figure 2) was designed for remote control. For this reason, the requirements for operational stability, reliability and safety were set to a high standard and the optical and image acquisition equipment were chosen accordingly for a new observatory.

Remote control of the equipment was achieved through an Intel NUC (Next Unit of Computing) computer (Intel NUC, 2024), which hosts all the control software for the system (dome, mount, cameras, focusers, filters, motorized caps), using AnyDesk Remote Access (AnyDesk.com, 2024) - a software for remote control between two computers via the internet.

The operating system used is Microsoft Windows 10 Professional (Windows

10 Pro, 2015), which is compatible with almost all the necessary programs.

For image acquisition, dome control, focuser control and mount control, we used MaximDL 6 (MaximDL, 2018) as the command software. Using drivers provided by the ASCOM (Ascom, 2024) platform and proprietary software from the mount, dome and focusers, MaximDL can control all elements of our setup.

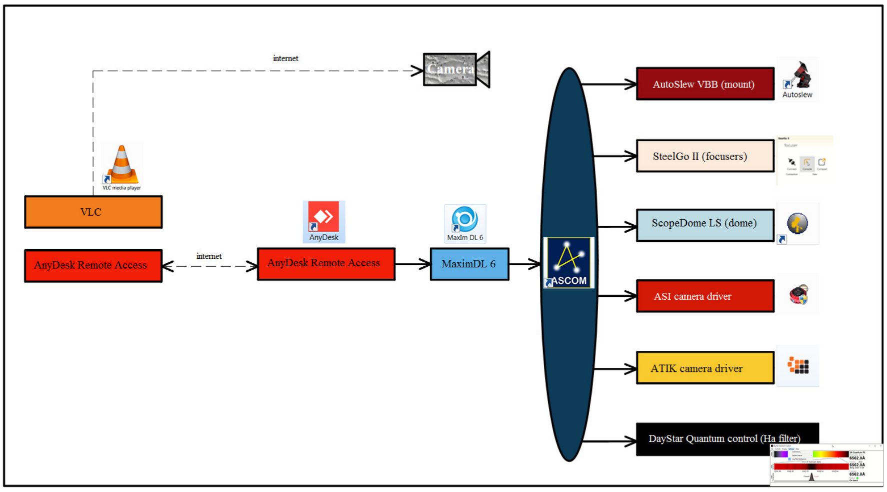

Fig. 2 – Connections diagram of different components from solar observatory.

The dome in which all the equipment was installed is a 3 meter SCOPE DOME (ScopeDome.com, 2013) and ScopeDome Arduino Card (ScopeDome.com, 2024), fully automated. The mount used is a direct-drive type with encoders, from Astrosysteme Austria – model ASA DDM85. The high load capacity of this mount (85 kg without counterweights) provides freedom for choosing equipment.

To effectively conduct observations, we decided that our system would consist of 3 telescopes mounted in parallel, each with the role of capturing images at a specific wavelength or passband. This type of image acquisition system is not new, being used in multiband night astrophotography and for imaging fields of view larger than one telescope can obtain in a single frame - the English project DRAGONFLY, (DRAGONFLY, 2019) is an example in this way.

Our calculations for various combinations of optical systems and camera sensors were made with a special program Field of View Calculator (Field of View, 2024) (Figure 3) and led us to our final chosen system, which provides full disk images of the Sun, at a sufficiently high resolution and at an optimized F/D focal ratio, so that we can use Baader's telecentric system TZ3 with the Hα filter (Baader telecentric systems, 2024).

The telecentric system TZ3 is necessary when using the Hα filter to send light rays through the filter as close to a parallel beam as possible, so that the focal ratio is F/30.

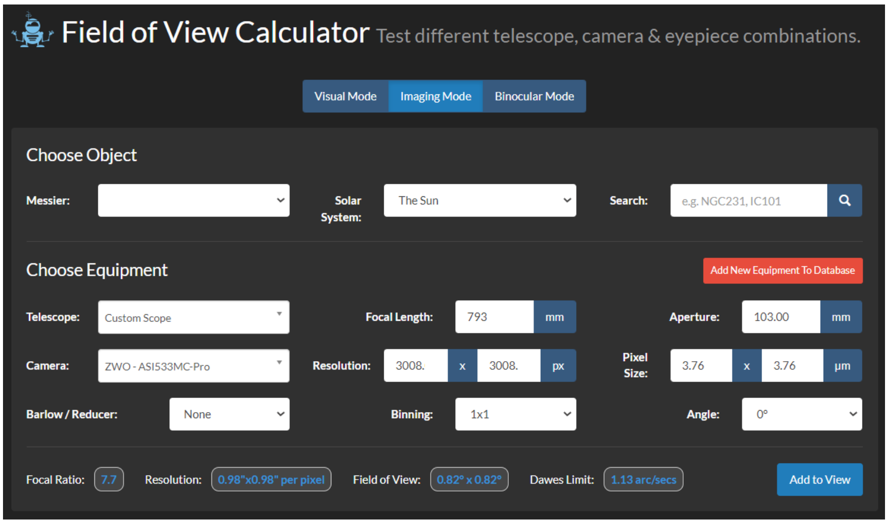

Fig. 3 – The software Field of View Calculator for testing combination between various telescopes, cameras and eyepieces.

These were the main criteria for choosing the telescopes. Based on them, we opted for VIXEN SD 103S refractors (VIXEN, 2024). This model uses ED APO objectives with a diameter of 103 mm and a focal ratio of f/7.7, good enough in combination with TZ3.

At the Bucharest Observatory, observations are made in white light (WL) at the photosphere and in the Hydrogen-alpha (Hα) line at the chromosphere. We proposed two instruments for these observations at the new observatory. In addition to the solar station in Bucharest, we introduced a telescope for observations of the Calcium-K (Ca-K) line, which forms at an intermediate portion of the solar atmosphere, located between the photosphere and chromosphere. This filter is supplied by Lunt. It is a filter that comes in straight extension tube for 2$''$ focuser and have a bandwidth of 2.4 Å for Ca-K line. Therefore, to observe the Sun as comprehensively as possible, we decided to use 3 identical telescopes, each with its own camera and its own light filtering system. Also, to ensure consistency in image acquisition, we chose cameras in such a way as to have an almost similar field of view in all three images obtained in parallel.

We chose ZWO ASI 533MM (Zwoastro ASI, 2024) cameras for WL and CaII-K and ATIK APx60 (ATIK, 2024) for Hα. ASI 533MM is an amp-glow-free CMOS camera, with a resolution of 9 Mp (megapixels) and a square sensor (3008x3008).

The camera can be cooled to 35 degrees below ambient temperature and has a very low read noise (1.0e). Data is downloaded through a USB 3.0 port, allowing a download cadence of 20 fps at maximum resolution (bin 1x1). The camera has a 14-bit color level resolution (*i.e.*, 16384 shades of gray), large enough for the intended purpose of taking images of the Sun. The second camera, ATIK APx60, is a full-frame CMOS camera (9576 x 6380 - 60 Mp resolution), amp-glow free, high quantum efficiency, read noise of 1.2 e and a 16-bit ADC (2^{16} = 65536 levels of gray), able to be cooled to 20 degrees below ambient temperature.

Both camera types are the latest generation, with back-illuminated sensor technology, making the quantum efficiency reach 90% in the 550 Å wavelength area for ATIK and 92% at 450 Å for ASI.

3. CONSTRUCTION OF THE TELESCOPE SYSTEM

Several improvements had to be made to the opto-mechanical system of the refractors. The original focusers of the instruments were replaced with Baader SteelTrack 2” motorized with Steel-drive II (Baader SteelTrack 2”, 2024), which allows a load of up to 8 kg under conditions of 3 microns precision in terms of focusing resolution. The focuser also allows for temperature compensation, with the possibility of setting the HOME position due to an included Hall sensor. Changing the focuser was necessary because the image acquisition equipment (camera, filters, adapters) is quite heavy, especially for the Hα telescope. The Steel-drive II automation is connected to the computer via USB, so the focusing adjustment can be made remotely.

To ensure that the optical system is functioning according to our requirements, we designed and created a subassembly for mounting and aligning the refractors on the same axis. The optical tubes were installed using special alignment rings for adjusting the optical axis. With the help of prismatic pieces made of duralumin, mounted between the respective rings, we managed to create a quite stable and perfectly collimable assembly for the three telescopes, an assembly that we later reinforced with rectangular aluminum profiles, mounted between the rings at the top of the assembly. These profiles were later also used as support for additional elements introduced in our construction (linear actuator for the objective caps).

The equatorial mount was installed on a metal pillar, built previously, fixed at the bottom by a concrete support that is isolated by the dome floor to avoid vibrations. The pillar gives the whole system the necessary height so that the rear windows/cameras do not hit the floor. To protect the objectives of the three instruments from dust, a hinged cap (Figure 4) was constructed to simultaneously close all three tubes, operated by a linear actuator. The advantages of this setup include centered actuation on the cap and the use of an existing element - the rectangular aluminum profiles used in the alignment system's stabilization, as support for the motor.

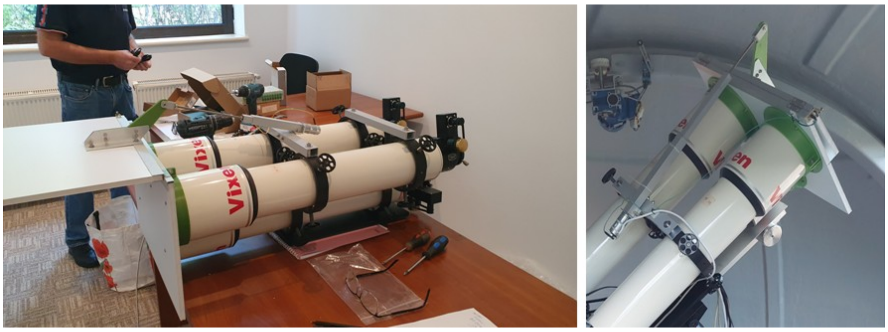

Fig. 4 – The hinged cover fixed to the three telescopes by plastic rings made by 3D printing and operated by an actuator.

The cap consists of two sheets of light composite panel, hinged together. One sheet is fixed to the ends of the three telescopes using specially constructed rings, while the other sheet forms the movable cap, operated by the actuator. Aluminum and 3D printed plastic were used for these components. The movable cap has self-adhesive velvet on the inside, providing a seal when closed.

A significant challenge was maintaining the Hα filter in low humidity conditions. We used the DayStar Quantum Professional Edition (DayStar Quantum, 2024) (Figure 5-left), a 32 mm scientific-grade filter with fine wavelength control, excellent spectral resolution (0.3 Å), and the ability to control temperature and correct positioning for the Hα spectral line. It comes with an RS-232 interface (Figure 5-right) and can be remotely controlled via a USB adapter and the manufacturer's application.

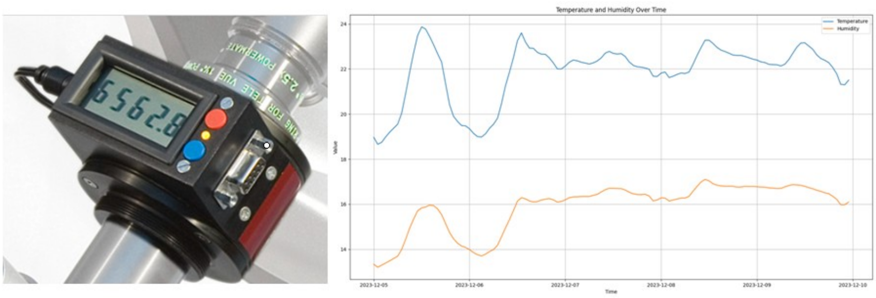

Fig. 5 – The DayStar Quantum Professional Edition (left). The variation of temperature and humidity over few days during December 2023 (right).

However, this filter is sensitive to environmental conditions, as it is made of mica crystals which are humidity-sensitive. Exposure to moisture can degrade its capabilities over time or even damage it. Therefore, protecting the filter against moisture was a crucial task.

The solution was to create a sealed enclosure (Figure 6) made of polypropylene pipe, large enough to accommodate the filter, external electrical connections, a humidity sensor and a few small silica gel packets. Tests showed that even when external humidity (in the dome) exceeded 85%, the humidity inside the enclosure hosting the filter remained within 20%, which is an excellent result.

Fig. 6 – The component parts of the sealed enclosure(left). Mounted sealed enclosure (right).

The Hα image acquisition refractor also requires an additional optical element, the Baader D-ERF (Dielectric Energy Rejection Filter) (Baader D-ERF, 2024). This is an aperture filter installed at the entrance of the optical system (objective lens) to stop solar light rays at wavelengths away from the Hα line, minimizing the energy entering the optical system to protect the filter.

In Figure 7 we can see the graph for the spectral transmission for D-ERF. Installing this filter on the Hα telescope required designing and building a special adapter for the objective cell.

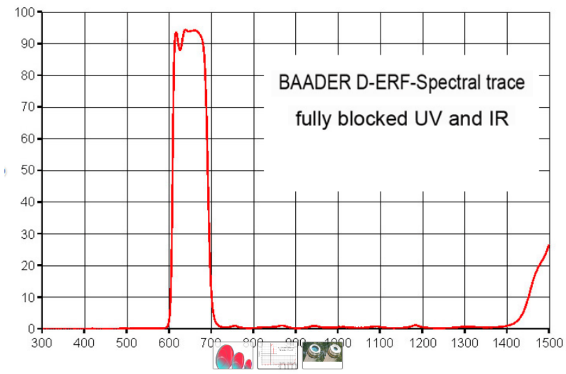

Fig. 7 – Spectral transmittance for Baader D-ERF.

Due to the large number of devices communicating with the computer almost simultaneously, it was necessary to use an industrial-grade, separately powered, 10-port USB3 hub. Through this hub, communications between the computer and all peripherals are managed, as shown in the diagram in Figure 8.

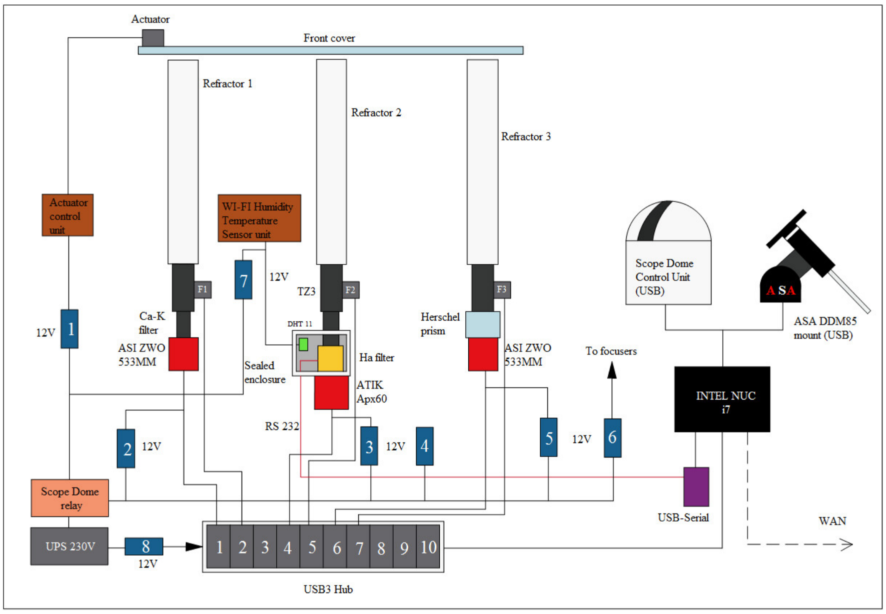

Fig. 8 – The Physical connections between observatory hardware.

4. INITIAL TESTS

The equipment has been acquired in the beginning of 2023, and from that moment, we building the system as it would eventually look and function. The first tests with the setup took place in the spring of 2023, in the courtyard of the Astronomical Institute of Romanian Academy (AIRA) in Bucharest. The metal pillar on which the telescopes were mounted was brought from Berthelot to Bucharest to perform all checks before transporting all the equipment to the dome (Figure 9).

The tests conducted verified and tested the following elements:

- the ability to collimate the three telescopes on the same target;
- achieving focus for each of the cameras used;
- cable management solutions (observing how cables move with the mount and how they might interact with various pieces of equipment, including the mount itself);
- the optimal way of communication between the computer in the observatory and a

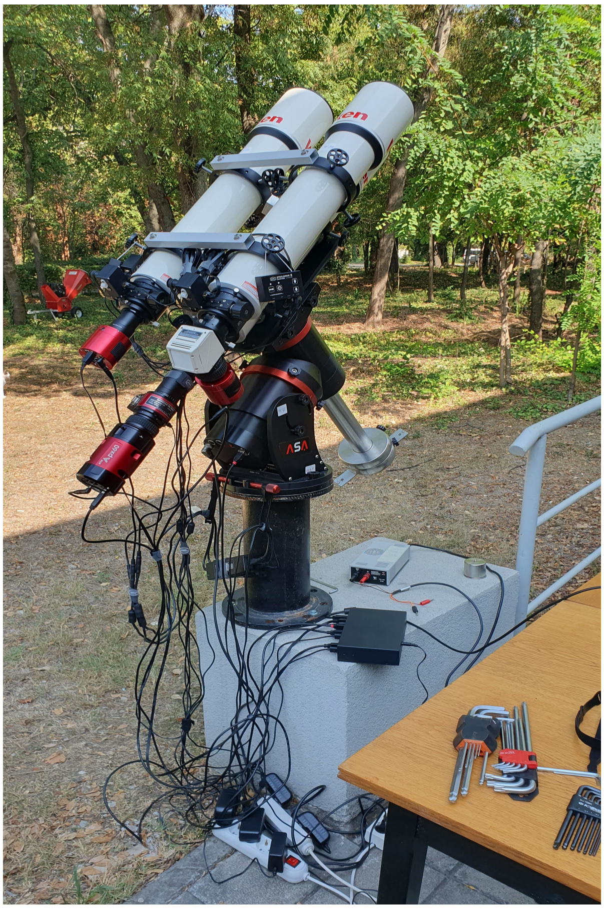

Fig. 9 – The telescopes mounted on the metal pillar at AIRA headquarter, for testing the system.

remote computer;
- the functioning of the USB hub in correlation with each device;
- minimizing the number of power cables by optimally using power supplies;
- testing the sealed enclosure for the Hα filter;
- the possibility of using the image acquisition software (MaximDL) simultaneously by multiple cameras;
- installing drivers for all used equipment to ensure no communication problems between devices and the local computer (NUC). The first image (Figure 10-left) was in white light, obtained on March 24, 2023, and later we also obtained images in CaII-K (Figure 10-right), the quality of the images and the framing of the field confirming the previous choices.

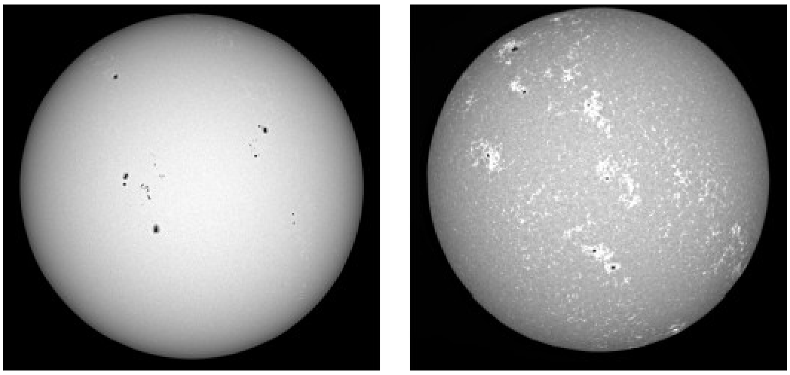

Fig. 10 – The white light (left) and CaII-K (right) test images.

5. INSTALLATION OF EQUIPMENT IN THE OBSERVATORY SITE

At the end of October 2023, the installation of equipment in Berthelot's solar dome (Figure 11) began. The assembly took place over 3 days, during which all equipment was installed and operational tests were conducted.

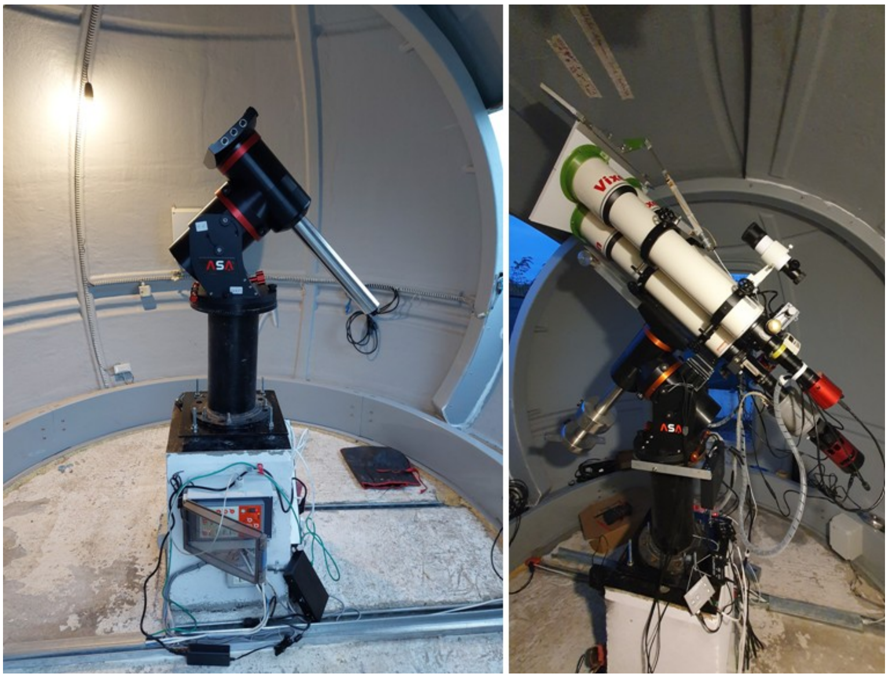

Fig. 11 – Pictures of the equipment installation in the Berthelot solar dome.

At that point, due to unfavorable weather, it was not possible to polar align the mount and synchronize the movement of the dome with that of the mount, so that the mount would always ”look” through the dome’s shutter.

Subsequent visits was made at the end of November to remedy minor unresolved issues, but the main problem - polar alignment - wasn’t possible till the end of June 2024. Taking advantage of the good weather, we managed to cross this last important stage. Polar alignment was performed using an internal procedure of the mount’s own software. This procedure produces a pointing model using 3 stars at the same declination on one side of the pillar and another star on the other side of the pillar. This model tells us how many degrees in azimuth and elevation should be applied to point the mount towards the Pole. A second iteration of this process makes the accuracy of the polar alignment very precise.

The first images were taken on the night of June 18, considering some deep-sky objects. After each exposure to one object, by moving the telescopes to the next object, the latter is almost in the center of the field of the camera’s telescopes and this was an indication that the mount is correctly installed and working well.

The set-up is operated remotely using the AnyDesk program. The NUC calculator works 24/7 and can be accessed at any time from our offices in AIRA.

Figure 12 shows an example of operation where the dome interfaces and the Hα filter can be seen. The bottom graph is to verify the filter is centered on Hα band.

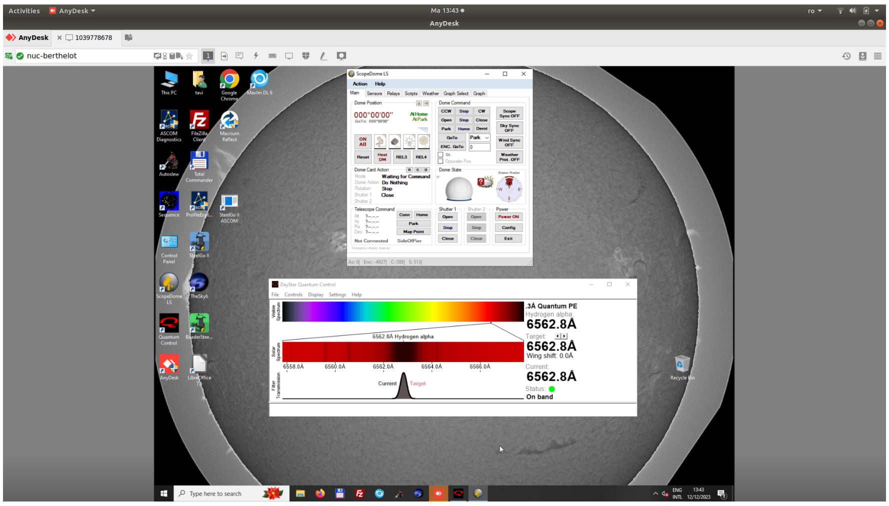

Fig. 12 – The remote operation of the system (Hα filter and dome).

Figures 13 and 14 show images of the Sun in Hα (inverted image), white light and CaII-K.

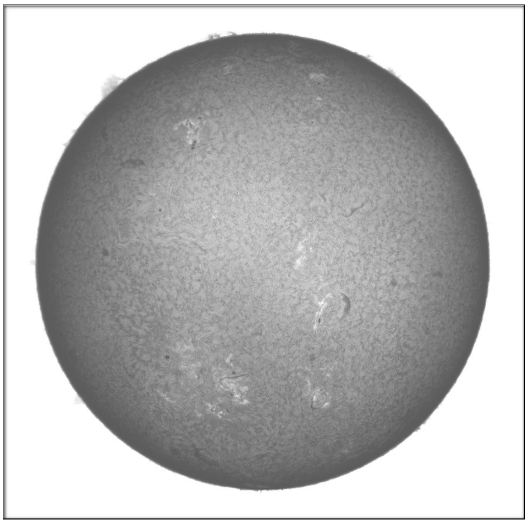

Fig. 13 – Sun in Hα, inverted for a good visualization of both filaments and proeminences.

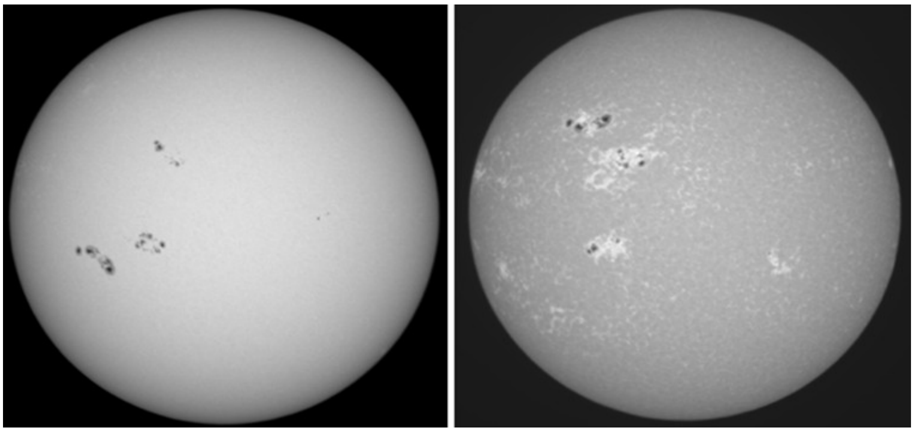

Fig. 14 – Sun in white light (left) and Sun in CaII-K (right).

6. CONCLUSIONS

The decision to build and equip the new solar observatory at Berthlot was a very good one, as the solar station in Bucharest is old, with physically worn equipment, requiring costly major repairs to the dome and mount. Also, the astroclimate in Bucharest is becoming increasingly unfavorable due to dust, exhausts, and atmospheric turbulence caused by the proximity to a busy road.

The Berthelot solar observatory is in an initial phase of operation, additional adjustments need to be made:

- perfect twinning of all telescopes (the white light scope is the one after which the pole setting was made and the other two scopes must be perfectly aligned after this. The Hα scope especially requires this adjustment;
- rotating the glasses so that we have the Sun correctly positioned in the images;
- tests to be done with an alternative image acquisition program, to avoid conflicts between equipment control software, which are of different generations and are optimized for different versions of Windows;
- integration into the automatic system and the dome. Currently, the dome cannot be activated automatically, because the control software (MaximDL) closes itself after the first activation of the dome;
- adding a finder camera to the system. Having a wide field, it is easy to find the Sun in the field if for some reason the mount is out of sync with the real sky;
- installation of a second surveillance camera, mounted near the dome hatch, so that we have visibility of the telescope from all directions, in case of emergency.

Testing of the remote controlled system is ongoing. Adjustments were made and the work procedure was developed for a complete observation session. Also, a special procedure has been developed for resuming operation in case of interruptions.

The software pipeline for the processing of Level 1 images and the creation of the database of observations available online is in the works.

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