Optical, laser and processing capabilities of the new Polish Space Situational Awareness Centre

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ABSTRACT

In January 2019 Poland has become a member of the European Union Space Surveillance and Tracking (EU SST) consortium. Under the management of the Polish Space Agency, a national Space Situational Awareness Centre (SSAC-PL) is being established. SSAC-PL will be responsible for operational obligations of Poland due to its EU SST membership and will fulfill national goals. The current network of Polish SSA assets consists of nearly 20 globally distributed optical sensors and one laser ranging station. Several more sensors are under development and should become operational in the time frame 2019-2021. Sensor and processing capabilities are provided to SSAC-PL by several academic and industrial entities. We will review the current state of SSAC-PL, its capabilities and progress that has been made in the sensor and processing domain over the last two years.

1. INTRODUCTION

The core of the Polish SSA community is composed of four public research institutions, two from the Polish Academy of Sciences, Nicolaus Copernicus Astronomical Center (NCAC PAS) and Space Research Center (SRC PAS), as well as the Institute of Automation and Robotics of the Poznan University of Technology (PUT) and the Institute Astronomical Observatory of the A. Mickiewicz University (IAO AMU), three Polish companies Sybilla Technologies, Cillium Engineering and 6ROADS and a non-profit research foundation Baltic Institute of Technology (Baltech). In January 2019 Poland has become a member of the European Union Space Surveillance and Tracking (EU SST) consortium. Under the management of the Polish Space Agency, a national Space Situational Awareness Centre (SSAC-PL) is being established. The current state of SSAC-PL, its capabilities being provided by the industry and academia and progress that has been made in the sensor and processing domain over the last two years are described below.

2. OUTLINE OF RECENT SSA ACTIVITIES IN POLAND FROM POLICY AND LEGAL PERSPECTIVE

Below we will concentrate mostly on describing the SST-related activities undertaken in Poland, although it should be noted that there were also recent interesting developments within the Near Earth Objects (NEO) and Space Weather (SW) components. As it is only a brief outline, we will only refer to the recent 5 years in which significant developments in policy requirements and legal provisions have occurred.

Legal and policy basis for SSA activities in Poland. From the legal perspective, the first statutory law act which contained direct reference to the SSA type activities in Poland was an Act of 26 September of 2014 on the Polish Space Agency[1]. The Act established Polish Space Agency (hereinafter POLSA) as legal entity in the form of a governmental executive agency as well as defined the Agency`s mandatory (legal) tasks. One of those tasks which was described in article 3 paragraph 16 letter c) of the Act, has been formulated as an "outer space observation". As a result, for the first time within the Polish legal system, the public entity was directly tasked with performing activities related to the SSA domain. The said provision together with an accompanying policy document described later in the text, have been a basis of all activities in the SSA area which have been undertaken by POLSA in the recent 5 years.

It is worth to highlight that par. 16 of the art. 13, in general, refers to the tasks related directly to the defence and security area – therefore from the beginning, all the SSA activities in Poland have been defined as having a clear military – or at least dual use – dimension. That, however, does not precludes or forbids the utilization of SSA services for civilian and commercial purposes and their importance for the development of a space sector within the country's economy.

It also needs to be mentioned that recently (July 2019) the Act on Polish Space Agency has undergone some changes, mainly placing the Agency under the supervision of the Minister of Entrepreneurship and Technology, as the highest governmental authority responsible for the space sector in Poland. However, the "outer space observation" and the corresponding development of national SSA capabilities still remain within the POLSA area of responsibility.

On the policy level, the most important document which refers to the SSA area is "*Polish Space Strategy*"[2] (hereinafter Strategy). It was prepared under auspices of Ministry of Entrepreneurship and Technology and accepted by the resolution of the Council of Ministers on the 17th of February 2017 entering into force on the following day. The Strategy establishes several particular goals to be reached in regard to general space-related activities in Poland, one of which is "*Development of national security and defensive capabilities using space technologies and satellite techniques*". Under this particular goal, the Strategy identifies "*Development of the national SSA system*" as a one the four key "*directions of intervention / tools of implementation*" to be undertaken / used by the public administration (mainly by POLSA).

As it was in the case of article of the Act on Polish Space Agency, the Strategy clearly recognizes the security and defence dimension as well as the dual-use nature of SSA capabilities. On the other hand, the Strategy also sees the development of the national SSA system as an opportunity for strengthening the space sector in Poland. It is assumed that the development of the national SSA system will be based on the utilisation of the already existing assets (capabilities) and broad cooperation with Polish commercial companies as well as with certain academia institutions – with the Agency foreseen as a main governmental actor. Finally, it needs to be highlighted that the enhancing national SSA capabilities is in alignment with other directions of intervention mentioned within the Strategy namely "*strengthening of (international) bilateral cooperation*" and "*increasing participation in multilateral international cooperation*". Establishing and maintaining good relations and collaboration on joint projects with other countries involved in SSA activities is seen as important part of the development and operation of the national SSA system.

Taking into account both the legal provisions in force and adopted strategic documents it can be said that in Poland SSA activities in general - and the development of a national SSA system in particular – are recognized as having a clear security and defence nature with a strong potential for being instrumental to the economic development of the national space sector, as well as presenting a good opportunity for increased international cooperation.

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[1] Dz.U. 2014 poz. 1533 – Legal Journal of 2014, position 1533

[2] https://www.gov.pl/web/przedsiebiorczosc-technologia/polityka-kosmiczna

Recent SSA capabilities developments in Poland. Given the above-mentioned roles and responsibilities as well as policy requirements, the Polish Space Agency has concentrated its efforts in the SSA area in three directions:

- development of the national SSA system based on existing capabilities and assets;
- becoming a member of the EU SST Consortium and participation in its activities;
- development of good bilateral relations with several like-minded countries (e.g. USA).

In order to develop a national SSA system, the Agency has created an SSA Operational Centre (SSAC-PL) within its organizational structure. Its main tasks include: gathering data from the SSA assets, tasking the sensors with observations, processing of data received and provision of certain SSA services for the national purposes. SSA Operational Centre also directly cooperates with other nations operational centres as a part of EU SST Consortium activities. The SSA data is being provided to the Centre by the cooperating entities mainly commercial companies and academic institutions. They are jointly responsible for a global network of 17 optical telescopes and one laser ranging station located in Poland. This allows for good geographical coverage and almost continuous observations of space objects in orbital regimes ranging from LEO to GEO. In future it is foreseen that the existing network of sensors will be further enhanced by the addition of new sensors and upgrading capabilities of the existing ones.

As the international cooperation has been seen from the beginning as an important part of the development of SSA capabilities there was an intensive effort undertaken by the Agency and other governmental bodies in order to participate in an SST Support Framework programme of the European Union. The programme's objective is to contribute to ensuring the long-term availability of European and national space infrastructure, facilities and services which are essential for the safety and security of the economies, societies and citizens in Europe. Specifically, this is done by:

- assessing and reducing the risks to in-orbit operations of European spacecraft from collisions;
- reducing the risks relating to the launch of the European spacecraft;
- surveying and providing early warning of uncontrolled re-entries of spacecraft or space debris;
- seeking to prevent the proliferation of space debris.[3]

In 2017 Poland has formally applied for the participation in the Support Framework and was accepted as a participating Member State in December 2018. Due to the fact that on the executive level the collaboration within the programme is practically performed by the consortium of space agencies of the EU countries participating in the programme (EU SST Consortium) - the Polish Space Agency has been designated as a national entity who will join the consortium and will take part in its activities. Following the negotiations and the amendment of the Consortium Agreement, as from 11th January 2019, POLSA has formally become the full member of the EU SST Consortium. As it was mentioned earlier, SSA Operations Centre now directly cooperates with other nations operational centres as a part of EU SST Consortium activities.

Establishing and maintaining good bilateral relations with other likeminded countries who were already involved in the SSA area has also been identified as one of the factors decisive for the successful development of the national SSA system. For this reason, the Agency has undertaken several initiatives, from which one of the most important was establishing practical cooperation on the SSA field with the United States of America. The important milestone for this cooperation has been reached in April the 10th of this year when POLSA and USSTRATCOM signed an agreement on cooperation for the safety of space flight and the exchange of SSA data and services.

Plans for the future. Taking into the account that nowadays SSA related issues are gaining in importance it is foreseen that the Agency will extend its engagement in SSA activities in particular by further development of national SSA system. It will likely involve the extension of the scale of operations and functionality of the functions performed by the SSA Operations Centre as well as additions of the new sensors to network and upgrades to the existing ones. In the international context the Agency will likely continue its policy of openness for the possibilities of cooperation in the SSA area with other like-minded countries.

[3] https://www.eusst.eu/project/sst-decision/

3. SENSORS

The network of optical and laser sensors available to SSAC-PL is shown in Fig. 1 and 2. It is composed of one laser station and 17 optical sensors already operational and 3 under development: Panoptes-1AB (available Q1 2020, Baltech), Solaris-5 (Q2 2021, NCAC PAS) and PST3 (Q4 2020, IAO UAM). Most of the operational sensors were already described in previous AMOS technical papers by Konacki et al. 2016, Konacki et al. 2017, Kaminski et al. 2018a,b [1,2,3,4]. Panoptes-1AB is a double system composed of a unique TEC300VT-7DEG astrograph and a 0.5 m telescope. Solaris-5 is a new 1 m, wide-field (f/1.3) survey telescope. The telescope will offer a large for this aperture 2.7 × 2.7 deg field of view. Panoptes-1AB and Solaris-5 are described in detail separately in these proceedings by Rogowska et al. 2019 [5]. PST3 is a cluster of telescopes composed of 2 survey telescopes and 3 tracking telescopes. It was presented last year by Kaminski et al. 2018a [3]. Panoptes-1AB and PST3 will be initially deployed in Poland and later relocated to the southern and northern hemisphere. The plan for Solaris-5 is deployment in the northern hemisphere.

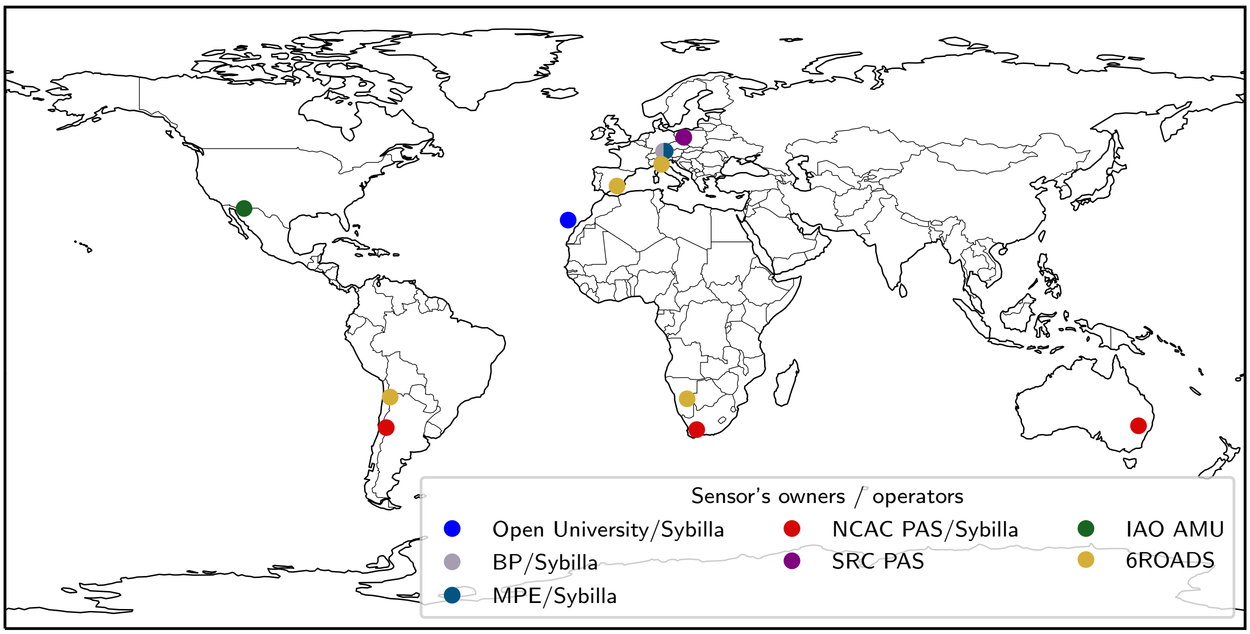

Figure 1: Global distribution of the sensor's network contributing to the Polish SSA system. BP – Baader Planetarium, MPE - Max Planck Institute for Extraterrestrial Physics, NCAC PAS - Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences, SRC PAS - Space Research Center of the Polish Academy of Sciences, IAO AMU - Institute Astronomical Observatory of the A. Mickiewicz University.

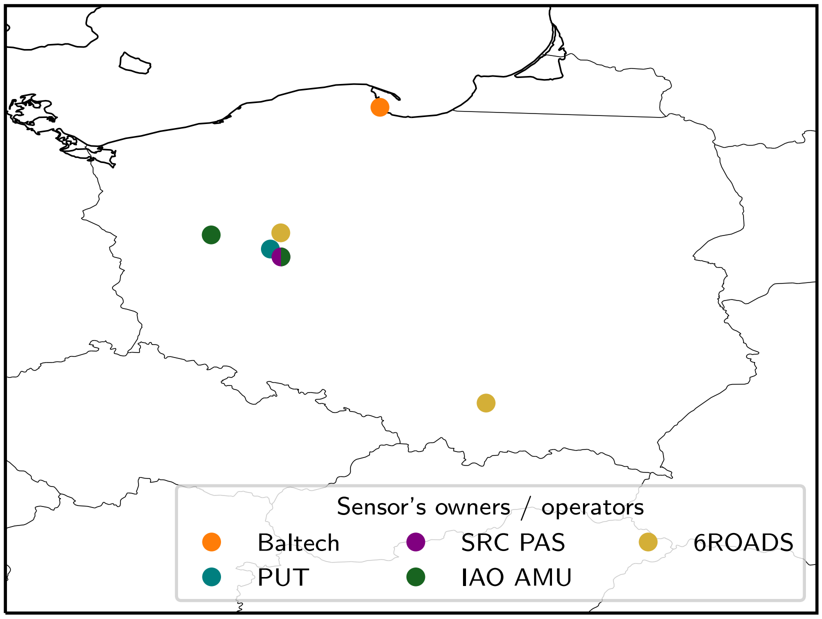

Figure 2: Current and future sensors contributing to the Polish SSA system located or to be located in Poland. PUT - Institute of Automation and Robotics of the Poznan University of Technology.

4. SMALL AND MEDIUM ENTERPRISE

SYBILLA TECHNOLOGIES

Sybilla Technologies (ST) is a software development company and integrator of turn-key robotic optical observatories, specializing in the "from sensor to TDM" chain of SST services. Present on the market since 2011 with an excellent relation with hardware manufacturers and distributors, working closely on introducing new products and optimized, integrated full solutions. The company has either built or contributed significantly to the creation of 12 robotic observatories on four continents with 4 more to come in next 2 years. Sybilla continues the work with various customers as a supporter, operator or consultant, ranging from research institutions through universities to space agencies and commercial companies to provide the best possible data from available sensors with minimal human effort, allowing for large networks of sensors to be created and to work as one.

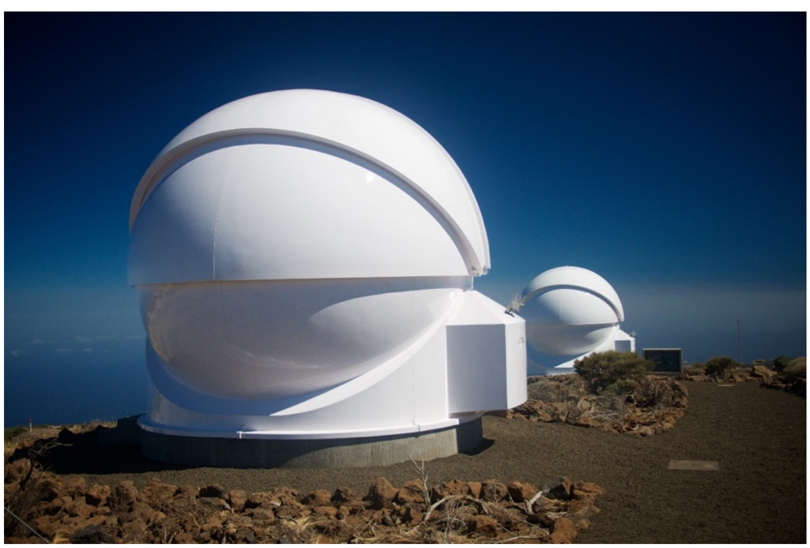

Figure 3: The Open University Pirate and Coast observatories in Tenerife.

ST staff of Sybilla Technologies are highly qualified experts in the development and maintenance of software solutions for autonomous robotic telescope networks with a thorough understanding of the scheduling, scientific data evaluation and analysis processes. Sybilla Technologies employs active researchers in the field of precise photometric and astrometric measurements who provide the company with a unique insight into the above subjects of photometric and astrometric astronomy and yields in the know-how of astronomical data reduction.

The company has experience in working with ESA (10+ projects) in the NEO and SST domains. For the Project Solaris and Panoptes network Sybilla actively develop low-level tasking, high-level scheduling and operation of the networks, data transfer, reduction and analysis software which produces hardware limited precision in photometry and astrometry. Sensors usually reach a few millimagnitude precision with aperture photometry on scientific grade equipment and 0.5 m aperture telescopes with subpixel astrometric accuracy well below 1 arcsec. The total number of processed and archived observations is close to the 12 000 000 frames and 60 TB of data.

ST is a company whose goal is to create user-friendly and intuitive software solutions for robotic observatories, data analysis and dissemination. Developed software is not only the code which performs certain tasks, but it also focuses on the details and brings attention to ergonomics of the product.

The company's resources include: 15+ engineers, access and operation of the network of 12 optical sensors. A wide range of in house developed products covering full cycle from optical sensors scheduling through autonomous data acquisition in robotic observatories to data calibration, storage, analysis and visualisation with output in a raw or TDM format.

Among the currently available products offered by ST are: Abot Suite - integrated and layered control system for the observatory (device drivers, device services, aggregation services, gateway), whose main capabilities are:

- management of the observatory covering the control of individual devices from the control computer level and via the ethernet with the authorization and authentication system (OAuth, OpenID) using connection encryption, user login and password,
- automated observation and calibration with overview using a web browser in a local network or via the ethernet, with the possibility of planning and manual control of each component.
- automatic goal-oriented planning observations of artificial Earth satellites and space debris with web-based UI and command line interface.

Astrometry24.NET - astrometry and photometry of observed point sources as well as satellites and space debris for observations in sidereal and non-sidereal tracking modes with a precision of 0.5 pixels or better, for objects with a signal-to-noise ratio higher than 10, within seconds from acquisition on desktop PC. Control of the astrometric reduction process from the level of web browser, command line or in automated pipeline. See [15] for more details.

LightStream - module for basic data reduction of optical data (dark, bias, flat correction).

AstroDrive - storage, visualization and analysis in the web browser of optical observational data. Statistical analysis in terms of histogram, value of min, max, average, standard deviation, position of centroid, measured flux with background subtraction of streaks and point sources. Software hosting service provided within the infrastructure, with web UI, Command Line Interface (CLI) and Application Programming Interface (API) access. The stored data (TDMs, FITS files) can be searched with their basic properties like name, directory but also via stored metadata (coordinates, target id, type, etc.).

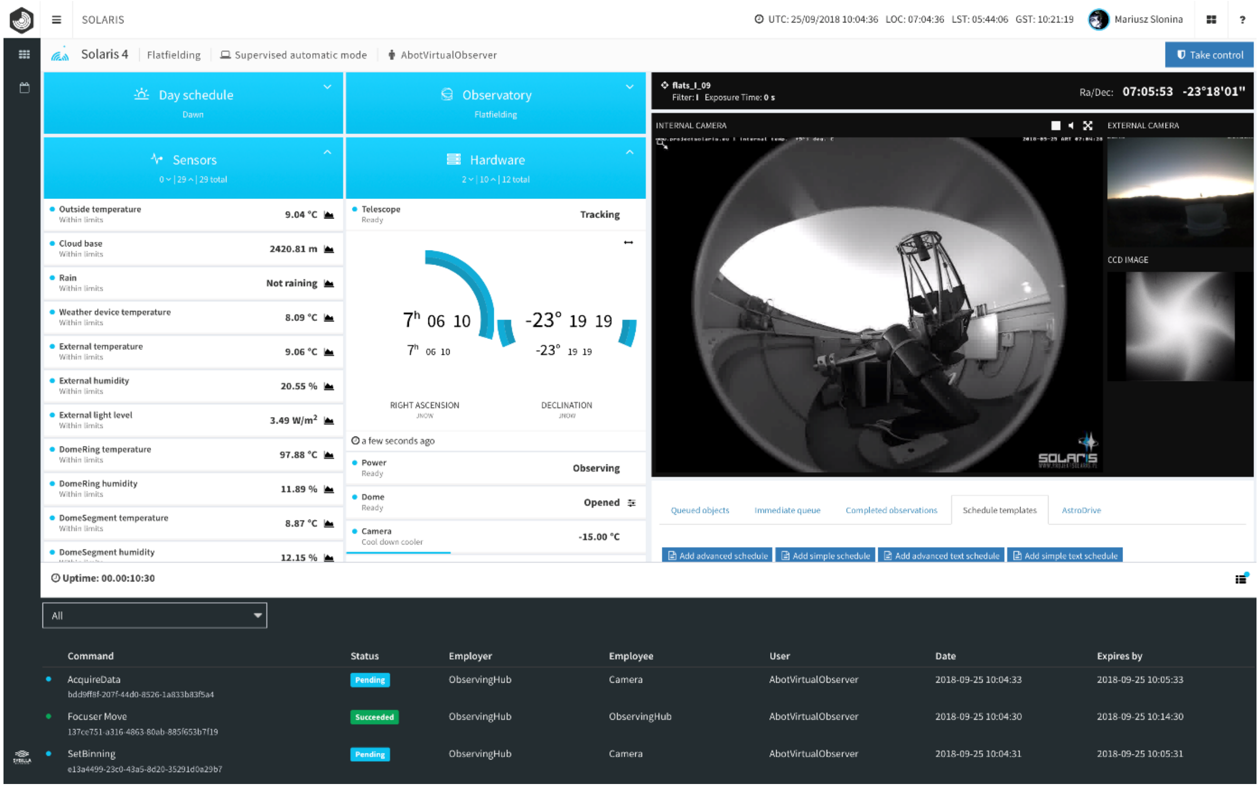

Figure 4: Abot level 3 web UI showing up to date status of the controlled sensor (Solaris-4, NCAC PAS, Argentina), live audio and video from the CCTV camera, up to date scientific images are displayed too. Each component is visible and historical, pending commands are also shown. This single page allows for efficient monitoring and control of the sensor. Sensor works in autonomous mode and human supervision is not required in normal mode where the sensors executes scheduled observations.

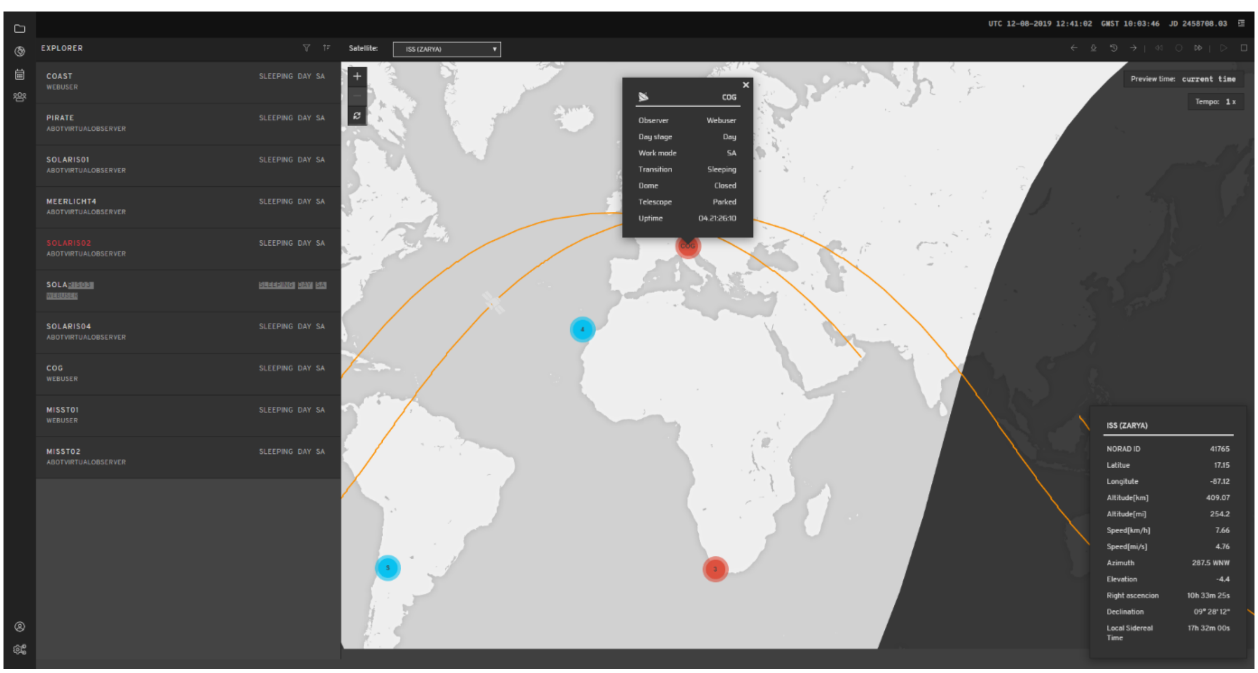

Figure 5: Central Hub for monitoring, tasking and data flow for heterogenous sensors networks (passive and active optical sensors, radars). Global view shows connected and available sensors, their properties and current status with day and night overlay. Single or multiple objects and their orbits can be displayed in the view.

AstroDriveSync - module automatically sends collected observations to the AstroDrive service. The program can be run in the console or as a service on the sensor's side. It is a permanently working component that starts and stops together with the operating system with throttling, filtering, resume, poison data detection, initial validation.

Ongoing and future ST activities include: WebPlan. Specialized sensor network scheduling environment for dedicated scenarios like catalogue maintenance of SST objects in sensor networks. Software developed within ESA contract WebPlan 4000125521/18/D/CT.

Visual Cortex. Processing of high-volume and high cadence data in near real-time in the domain of SST/NEO, including synthetic tracking and live feedback to scheduling system. Software developed within ESA contract Visual Cortex 4000127284/19/D/CT.

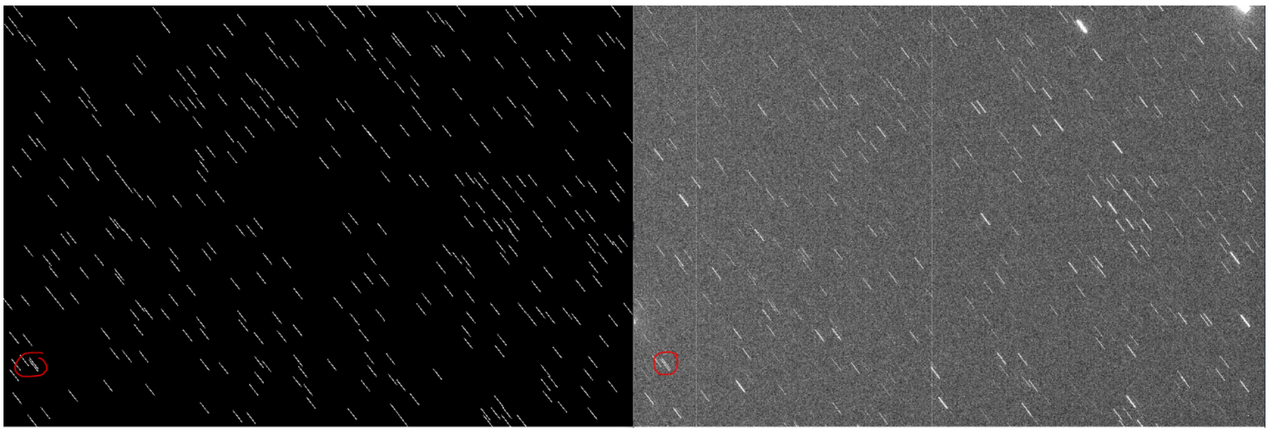

Figure 6: Fast and low SNR extraction algorithm taking into account close and overlapping sources. Binarized and real images shown next to each other.

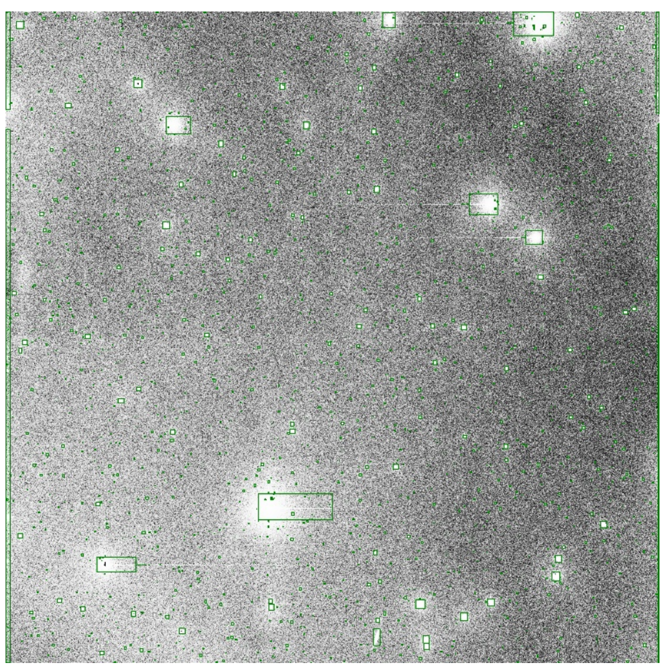

Figure 7: Fast, reliable detection and measurement (few seconds) of large FOV images with uneven background, saturation, artefacts, clouds.

MISST - Mixed reality and intelligent conversational agent interfaces for SST. Mixed reality interfaces and automated agents for optimized work with sensors, orbital data, collaboration and critical events handling with Microsoft HoloLens technology. Software developed within ESA contract Visual Cortex 4000123789/18/D/MRP.

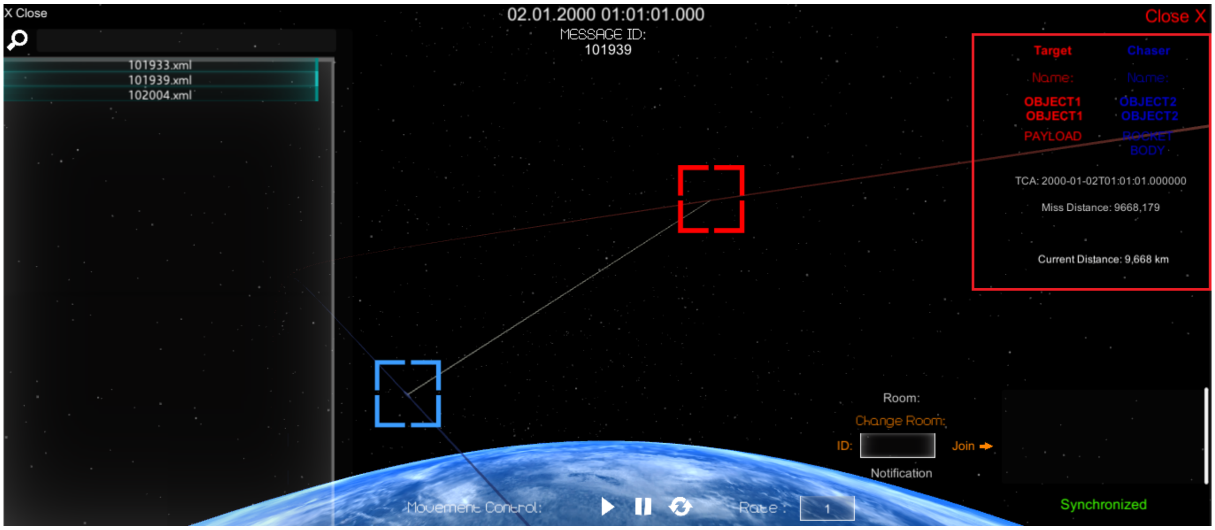

Figure 8: User Interface used for displaying satellite and situation properties.

Figure 9: A view menu for a Microsoft HoloLens-based NUI.

Figure 10: Received states of all observatory elements displayed (red indicates faulty state).

CILIUM ENGINEERING

Cilium Engineering, established in 2014 in Toruń, Poland, is a fully Polish-owned technological company working in the area of ground-based observing systems. Cilium's staff has contributed to the design, construction and commissioning of six optical observatories and delivered components to many others [6]. A staff of six specialists in the area currently work on several space-related projects, most of them funded by ESA. Cilium's portfolio includes hardware and software observatory safety systems, opto-mechatronics, custom sensors and HMI solutions, deployable embedded systems as well as proven observatory design solutions – from scientific idea to commissioning and operation. Instrumental and software projects realised at the company relate to various science topics: astrometry, photometry, spectroscopy, polarimetry, control engineering and data science.

One of the currently on-going, ESA-funded activities, is OmniSkyNET. The goal of the project is to build and deploy a network of distributed optical sensors to detect and observe re-entries of man-made objects. OmniSkyNET will be the first attempt to actually observe re-entries on regular basis and, possibly, characterize these events thanks to high frame-rate observations. As we have shown in extensive simulations [7], it will be possible to detect ca. 5 re-entry events per year with a 16-station network covering the area of Poland. This number could be more than doubled if the network is deployed in more favourable weather conditions. A single OmniSky station comprises four CMOS cameras coupled with 8 mm f/1.4 lenses for almost all-sky coverage. Data processing is done onboard with dedicated computing modules. The system follows the edge computing paradigm – high volume data streams from the stations is reduced on-board the devices and transferred to cloud services. These, in turn, integrate data from all stations in the network and are responsible for trajectory computation, data sharing and presentation.

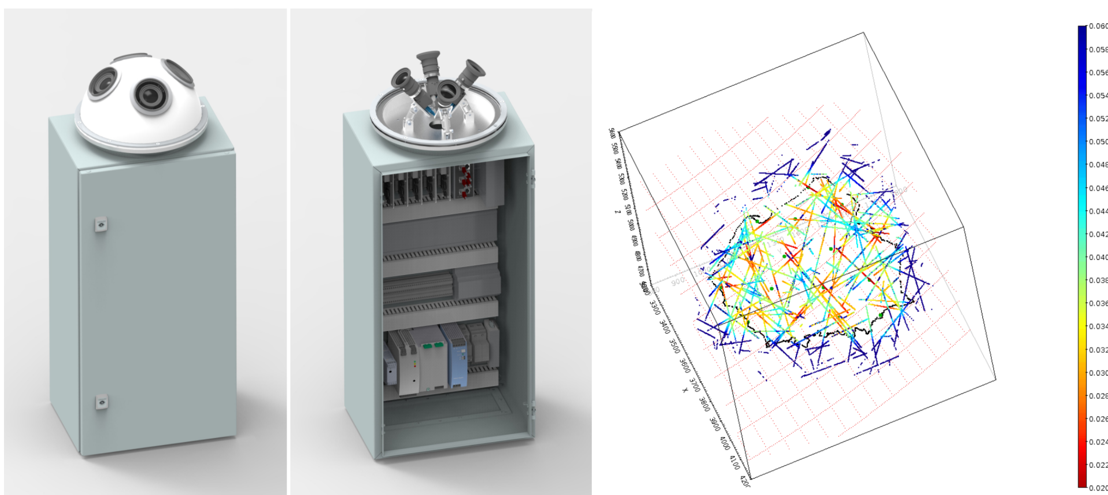

Figure 11: OmniSky station rendering (left). Network of 16 stations covering whole territory of Poland. Positional precision, color scale adjusted to show details of the most precise trajectories. X, Y and Z axes as well as the precision bar, are scaled in kilometers. Simulation time covers 10 years (right plot).

First operation results from one OmniSky station are expected early 2020. Two more stations will be deployed later that year. At the same time, existing stations from the Polish Fireball Network will be integrated into the network to test and verify data processing integrity.

6ROADS

6ROADS is a focused company that owns and operates a global network of telescopes to provide high quality data in the SST domain. The infrastructural core of 6ROADS is composed of six optical observatories located across the globe. As a company 6ROADS was established in 2016, although its experience can be traced back to 2003. Its headquarters are in Krakow and there are approx. 6 persons employed right now. It operates in 5 countries: Namibia, Poland, Chile, Italy and Spain (see Fig. 12). Their system of optical sensors allows for systematic surveillance and tracking of RSOs.

Figure 12: Telescopes of the 6ROADS global network. Polonia (Chile), Springbok (Namibia), Rantiga (Italy) and Idgrasil (Spain).

5. PUBLIC RESEARCH INSTITUTIONS

BOROWIEC LASER RANGING STATION OF THE SPACE RESEARCH CENTER, POLISH ACADEMY OF SCIENCES

The Borowiec Satellite Laser Ranging Station belongs to the Space Research Center of the Polish Academy of Sciences (SRC PAS) and it is the only such device in Poland and one of the few ones in the world working since the mid-80's. The Borowiec laser ranging station (CSLRB) started to track typical space debris targets, cooperative inactive/defunct satellites and uncooperative rocket bodies in the middle of 2016. Currently, the station is actively involved in the development of the Space Surveillance and Tracking programme, developed by European Space Agency (Space Safety programme) and development of the Polish capabilities in the SST activity supervised by Polish Space Agency. Figure 13 presents the main view of the station with the primary telescope, two laser modules and operator room. The station uses two independent laser modules, one is Lithuanian EKSPLA PL-2251 used for International Laser Ranging Service (ILRS) needs and the second is American Continuum Surelite III dedicated to space debris (SST programme). The detailed characterization of the system configuration can be found in the paper by Lejba et al. 2018 [8].

In 2018, the CSLRB station tracked 53 different objects, satellites and space debris (cooperative and uncooperative targets), with a total of 1857 full passes. 43 were satellites, 29 were Low Earth Orbit (LEO), and 14 were Medium Earth Orbit objects. 10 objects were typical space debris, in particular, defunct satellites from the LEO regime. These targets were observed within the framework of the Space Debris Study Group run by the International Laser Ranging Service (ILRS). A total of 483 space debris passes were performed. Information about the position and behaviour of space debris such as defunct satellites is very important from the point of view of future debris removal missions (e.g. ENVISAT). We need to know not only where it is, but also precise information about its rotation/tumbling and orientation in space. Laser measurements recorded by the CSLRB station support global research on the determination of space debris spin dynamics (ENVISAT, ERS-1, ERS-2, OICETS, SEASAT-1, TOPEX/Poseidon and others), which is essential to improve theories of the movement of artificial satellites. In 2019 the process of space debris tracking is continued and was extended by new targets from LEO regime (Chinese/Russian boosters). The AVG number of returns for one pass is from 10 to 43 and the AVG RMS is from 9.39 to 193.36 cm.

Figure 13: CBK PAN Borowiec laser station.

In 2017 the staff of CSLRB station has begun the development of the second independent optical-laser system, dedicated to the SST programme. The new system is based on an azimuth-elevation mount with a 65 cm Cassegrain telescope (Fig. 14) equipped with servo drives. These provide very fast tracking, with accuracy better than 1 arcsec and an RC 8'' guiding telescope equipped with two fast dedicated optical CMOS cameras. The whole system is controlled by multiplatform steering/tracking software (Fig. 14) supporting space debris/satellite prediction, real-time laser observations, system calibration, ADSB monitoring (Fig. 15), data post-processing and other functions. When fully implemented, the system will operate 24 hours a day, 7 days a week. Currently, the second setup can track, in optical mode, satellites from LEO to GEO regimes (Fig. 16 and 17).

Figure 14: The second optical-laser setup developed by the CSLRB (main telescope and operator room).

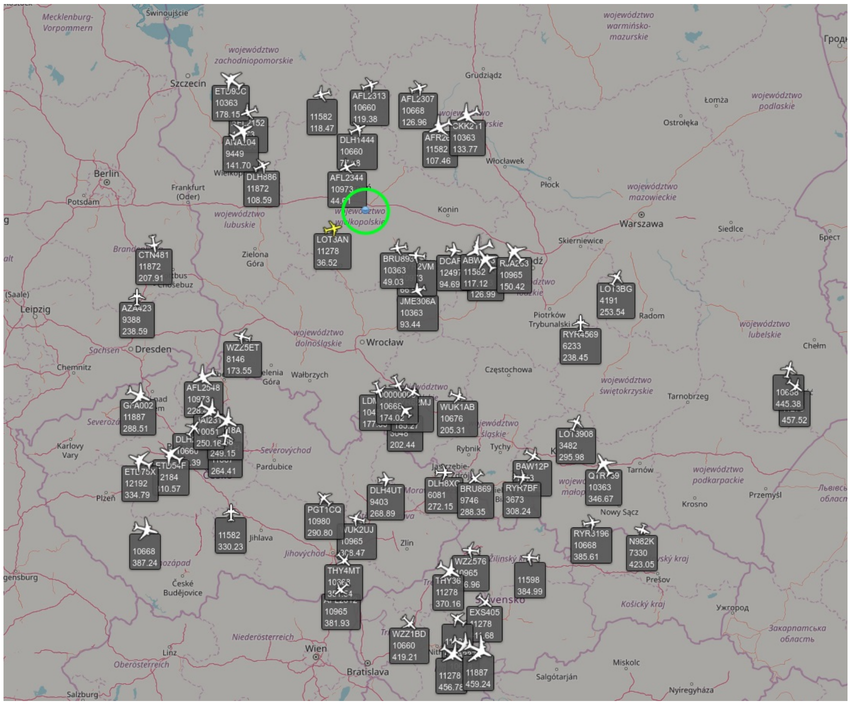

Figure 15: Screenshot of the ADSB system with a second optical-laser setup developed by the CSLRB.

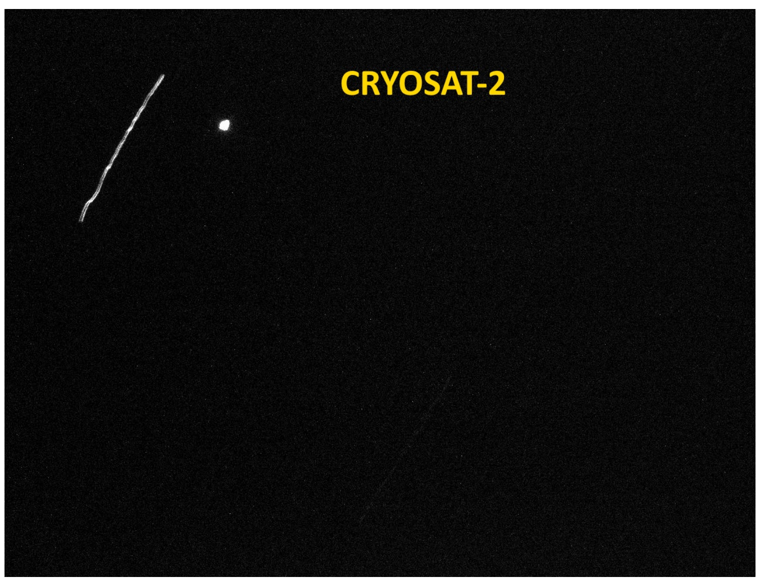

Figure 16: Optical tracking of the CRYOSAT-2 satellite (LEO regime) by the second CSLRB setup.

Optical measurements will be used to characterise space missions and SST activity. In the test phase, a special spectroscopic module was dedicated to recording the physical characteristics of tracked targets. The next step in the compose of the new CSLRB setup, planned for the second half of 2020, and its integration with a new powerful laser module (≥50W).

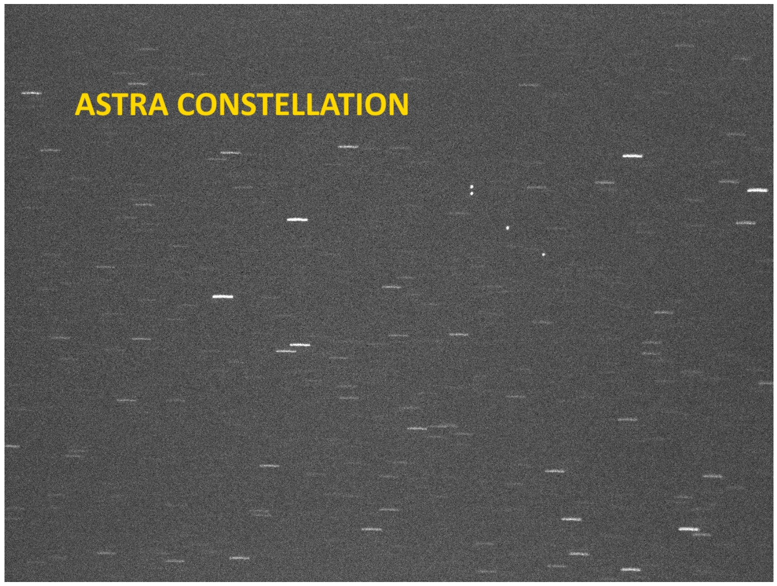

Figure 17: Optical tracking of the ASTRA constellation (GEO regime) by the second CSLRB setup.

At present, on the tracking space debris list of CSLRB station is several dozen targets, mainly Chinese and Russian boosters from LEO regime. Very interesting objects seem to be the Chinese boosters which give many returns even if picosecond 10Hz laser is used. This effect was observed many times for object with the NORAD number 31114. Probably this target is equipped with retroreflectors. More details can be found in the paper (Lejba et al. 2018). Another example is the object with the NORAD number 28480 (Chinese booster too), which can be measured relatively easily by means of picosecond laser with 10Hz repetition rate (confirmed by CSLRB station). In Fig. 18-21 the sample results obtained by CSLRB station in 2019 are presented. The measurements were processed by new software developed by CSLRB group as well.

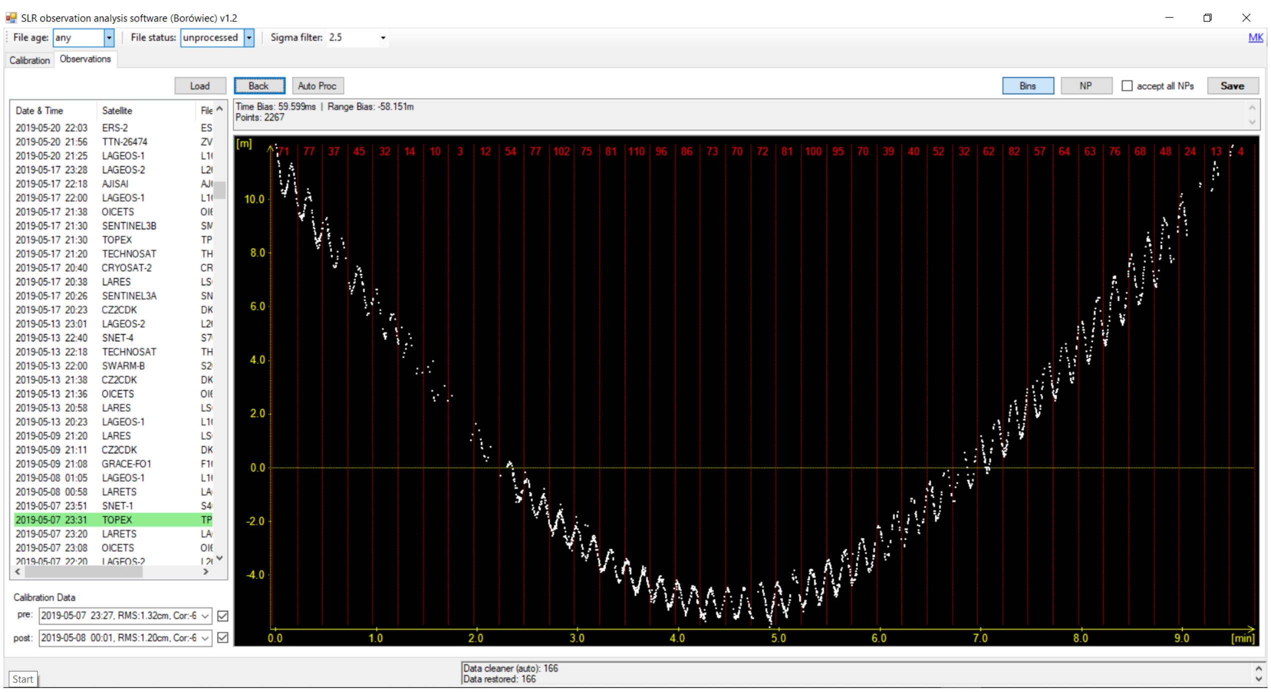

Figure 18: Laser measurements (after removing the noise) of fast rotating TOPEX-Poseidon (NORAD 22076).

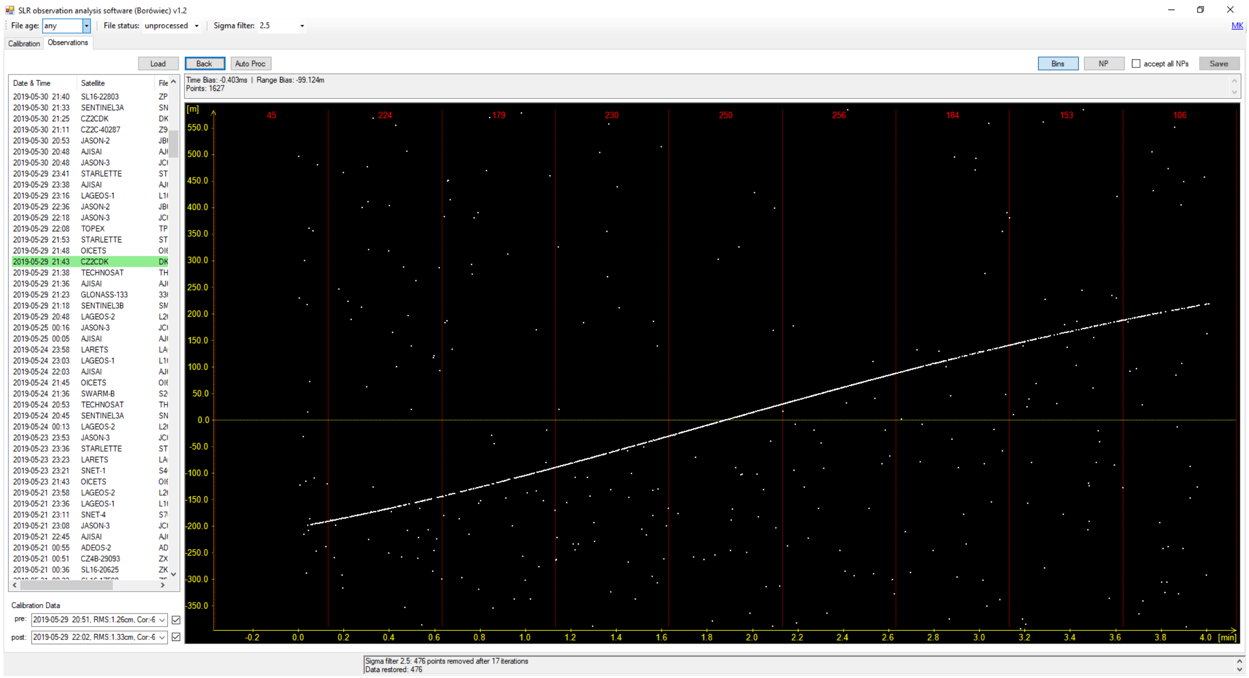

Figure 19: Laser measurements of Chinese booster Chang Zeng 2C (NORAD 31114).

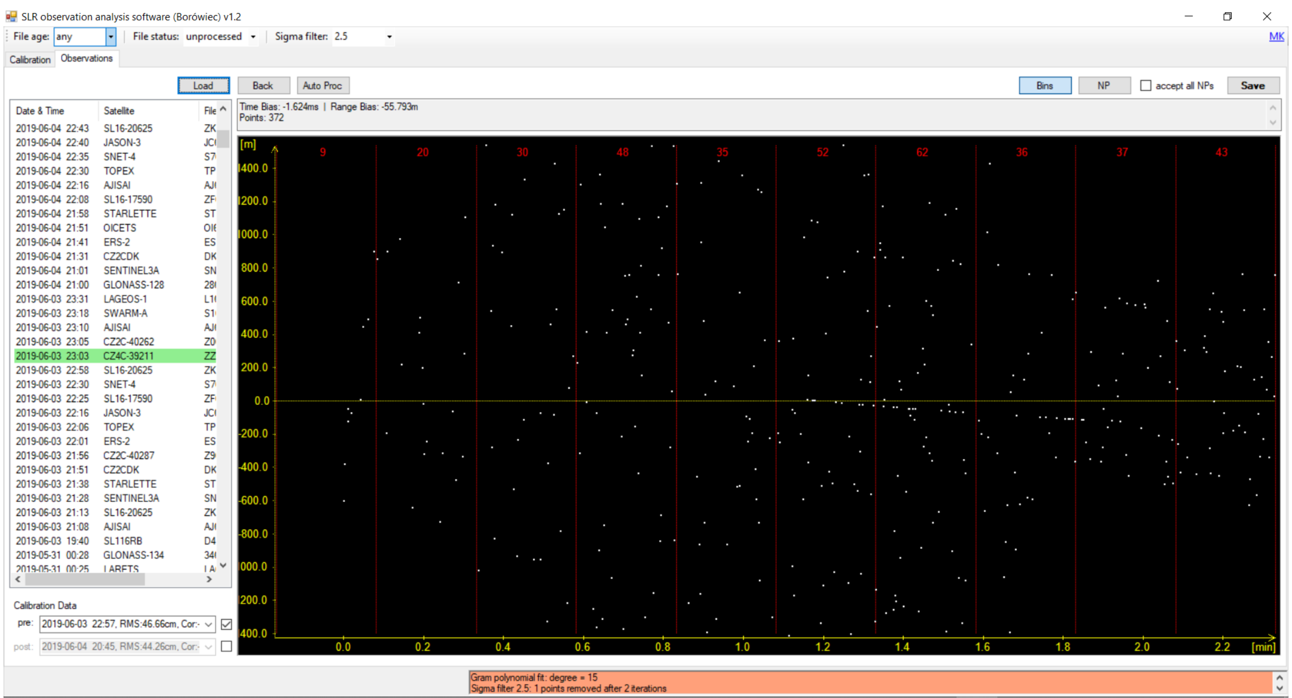

Figure 20: Laser measurements of Chang Zeng 4C (NORAD 39211).

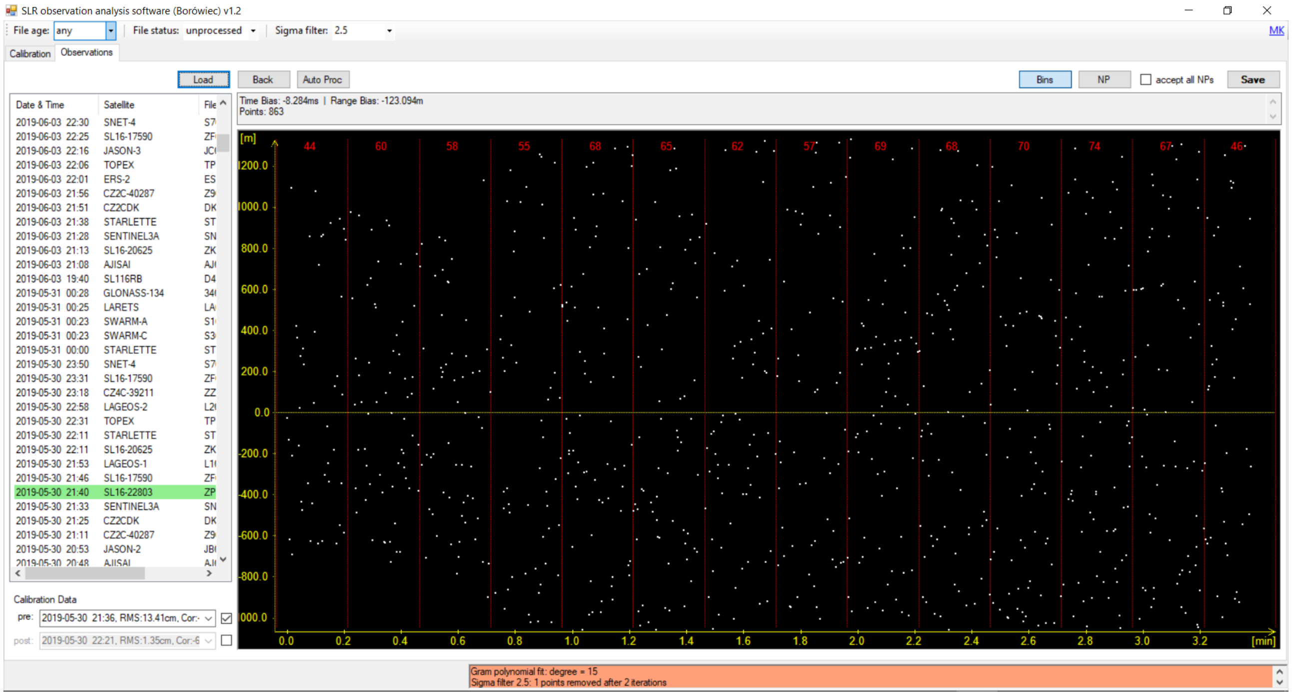

Figure 21: Laser measurements of Zenit-2 (NORAD 22803).

Another essential novelty in the activity of CSLRB station is installation of a new counter, event timer A032 (Fig. 22). This counter was installed and programmed at the beginning of summer 2019. Currently, stations test this counter in different configurations, including system calibration and real measurements of satellites and space debris.

Figure 22: New counter at CSLRB station – event timer A032 (test phase).

The research and development activity of CSLRB station focuses on SST. To increase the effectiveness of the space debris laser measurements (long distances – much over 1000km and tracking of the targets with RCS below 1m^2), the CSLRB station plans in the next step to correct the laser beam divergence on the output of the telescope, purchase and install new detector based on SPAD technology and much powerful laser with hHz repetition rate and energy of one pulse at the level of 500mJ for 532nm. It must be pointed out here, that the CSLRB station is using one telescope system for tracking of ILRS's and space debris objects. However, these tasks should be separated due to significant needs to track many objects, especially space debris targets which are a huge challenge for science and industry for next years. The advantage of the CSLRB group is fact, that the laser station develops the special security zone with a „restricted clause" which is being planned to use in the dual-use area. Additionally, the polish laser team has a security clearance issued by The Internal Security Agency (Poland Top Secret, EU Top Secret, Cosmic Top Secret and ESA Secret).

NICOLAUS COPERNICUS ASTRONOMICAL CENTER, POLISH ACADEMY OF SCIENCES

Nicolaus Copernicus Astronomical Center Polish Academy of Sciences (NCAC PAS) is the major astronomical institute in Poland. It was established in 1978. The main subjects of research include: stellar astrophysics, binary systems, circumstellar matter, dense matter and neutron stars, black holes, accretion processes, structure and evolution of active galaxies, cosmology, extrasolar planets. Astronomers from the Copernicus Center are involved in a number of major international observational projects such as: H.E.S.S., CTA (observations of ultra-high energy photons (TeV) via detection of Cherenkov radiation), Herschel (satellite observations in IR domain), SALT (Southern African Large Telescope), INTEGRAL, Fermi (satellite observations of gamma rays), LIGO-VIRGO (detection of gravitational waves). The ground station for the control of the first Polish scientific satellites BRITE PL1,2 is located and operated at the Copernicus Center as well. The ASTROCENT project is a new research initiative at the Copernicus Center in Warsaw. The new research unit will be a third section of the Copernicus Center. The research will focus on the detection of gravitational waves and dark matter using advanced technological instruments.

NCAC PAS owns and operates a global network of four robotic telescopes in the southern hemisphere "Solaris" that among others provides data for the SSA domain. Solaris nodes are located at the South African Astronomical Observatory (Solaris-1 and Solaris-2, see Fig. 23), Siding Spring Observatory, Australia (Solaris-3) and Complejo Astronomico El Leoncito, Argentina (Solaris-4). The telescopes were described in detail in previous AMOS papers [1,2].

Figure 23: Solaris-1 and Solaris-2 at the South African Astronomical Observatory (Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences).

POZNAŃ UNIVERSITY OF TECHNOLOGY – SKYLAB

Poznan University of Technology (PUT) offers education at 10 faculties that provide students with a choice of 27 fields of study. The university has over 20000 students and more than 1200 faculty members. The Institute of Automation and Robotics (IAR) is a part of Poznan University of Technology. The main research objective is to design and build robots and control systems that autonomously operate in complex environment. The Institute's staff is interested in the analytical approach to the design of control systems that cooperate in various scenarios that are inspired by real-life and industrial applications.

SkyLab (see Fig. 24), established in 2018 by IAR, is a fully-fledged optical astronomical observatory owned and operated by the Poznań University of Technology that has been designed to be a research laboratory with infrastructure to test new hardware and software solutions developed by a team of engineers, computer scientists and astronomers involved in space-related projects carried out at the University. The observatory is equipped with all necessary systems to allow remote, manual and fully automatic operation. Currently, the dome houses a custom-designed alt-az telescope mount designed for SST applications and a 0,5-m telescope. An overview of the observatory's infrastructure is presented in Table 1.

Table 1: SkyLab equipment overview.

Dome	3,5-m clamshell with 2-level panel floor
Mount	Custom alt-az with direct drive motors and absolute encoders with slew speeds up to 200 degrees/s and dedicated control rack
Imaging train	4K x 4K CCD cooled CCD camera with filter wheel (50 mm square Johnson filters) and rotating focuser
Telescope	0,51-m f/6.8 Corrected Dall-Kirkham
Control rack	Server-grade control computer, networking devices, remote power distribution units, UPS
Safety	Dual-weather station, ObsWach safety and HVAC system, internal and external IP cameras
Software	Custom telescope control software, Abot Suite and Abot SST for observatory automation

The vicinity of the university campus makes this research facility very attractive for research and development projects. Despite light pollution, the sensor successfully acquires SST data for test and evaluation purposes. It is a very valuable asset of Polish SST not only due to the engagement of highly-qualified research staff, but also thanks to the large student community that the site is accessible to, creating an additional benefit of increasing space situational awareness among them.

The custom-designed and built alt-az mount is the first SST-related project deployed in SkyLab. The goal of this initiative was to study possibilities of applying advanced control techniques to a very high dynamic range robotic system and explore new ways of optimizing the effectiveness of ground-based observing systems applied to SST activities.

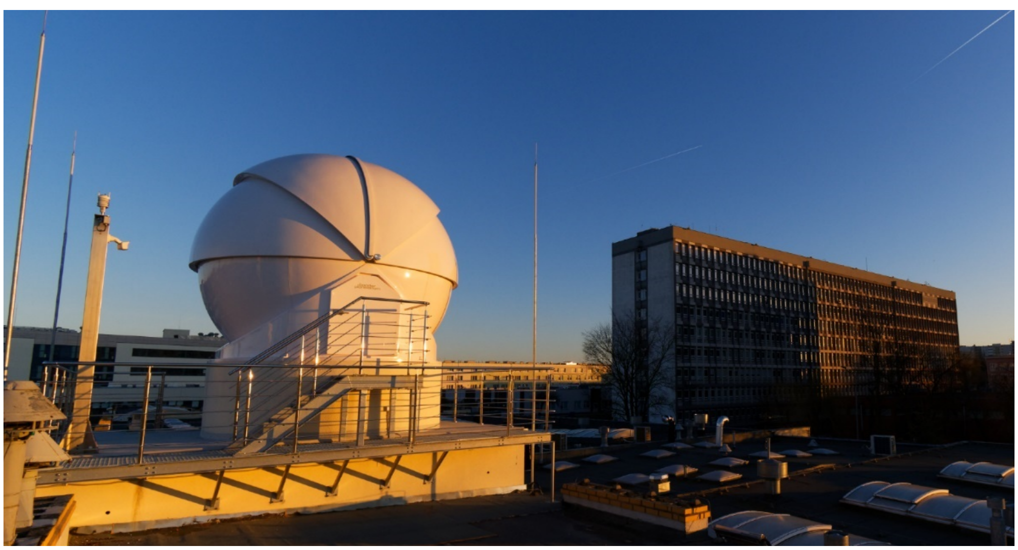

Figure 24: SkyLab, Poznan University of Technology.

INSTITUTE ASTRONOMICAL OBSERVATORY OF THE ADAM MICKIEWICZ UNIVERSITY

The Institute Astronomical Observatory of the Adam Mickiewicz University (IAO AMU, Poznań) is a research institution with roots dating back to the early 1900s when the idea to establish an astronomical observatory in Poznań emerged. IAO AMU has a long history of scientific activities in the areas of asteroids and comets observations and characterization, celestial mechanics, and observations of artificial satellites. Today, IAO AMU operates its own network the Global Astrophysical Telescope System (GATS) composed of two telescopes PST1 (Poland) and PST2 (USA, Arizona) with the third one PST3 under development. GATS is used among others for stellar astronomy and SSA purposes. The telescopes were described in previous AMOS papers [3,4].

BALTIC INSTITUTE OF TECHNOLOGY

Baltic Institute of Technology, founded in January 2016, is the idea of creating in Poland an interdisciplinary scientific and technological platform with a flexible form of operation and effective management structure, set apart from the traditional academic system. Since October 1, 2016, research projects implemented in the Foundation are co-financed from the budget of the Municipality of the City of Gdynia.

A consortium composed of the Baltic Institute of Technology, Cilium Engineering, and Sybilla Technologies is involved in "NEOPol: Polish polarimeter for NEO observations" project for the European Space Agency. The NEOPol project's goal is to build and validate in a laboratory setting a prototype polarimeter for Near-Earth Objects (NEOs) observations, together with a dedicated automated pipeline for polarimetric data processing and web service for data storage and visualization. When it comes to the assessment of NEO physical properties, polarimetry is one of the most effective tools to measure the albedo of NEOs and from that their spectral types, i.e. composition (see e.g. [9,10,11,12]). It also allows one, coupled with photometric measurements, to determine effective diameters of asteroids, which is crucial e.g. for assessing the result of a potential collision with the Earth or exploitation of raw materials. Studying objects by covering their complete rotation curves in terms of polarimetry and photometry makes it possible to determine the objects' shapes and the distribution of different materials on their surface. The project will provide both an instrument dedicated for NEO observations as well as tooling for an efficient analysis of polarimetric NEO data, in preparation for the processing of large amounts of data from the new generation of optical sensors where up to 1000-fold increase in data generation rates is expected (see e.g. [13,14]), which naturally puts the emphasis on automation and efficiency.

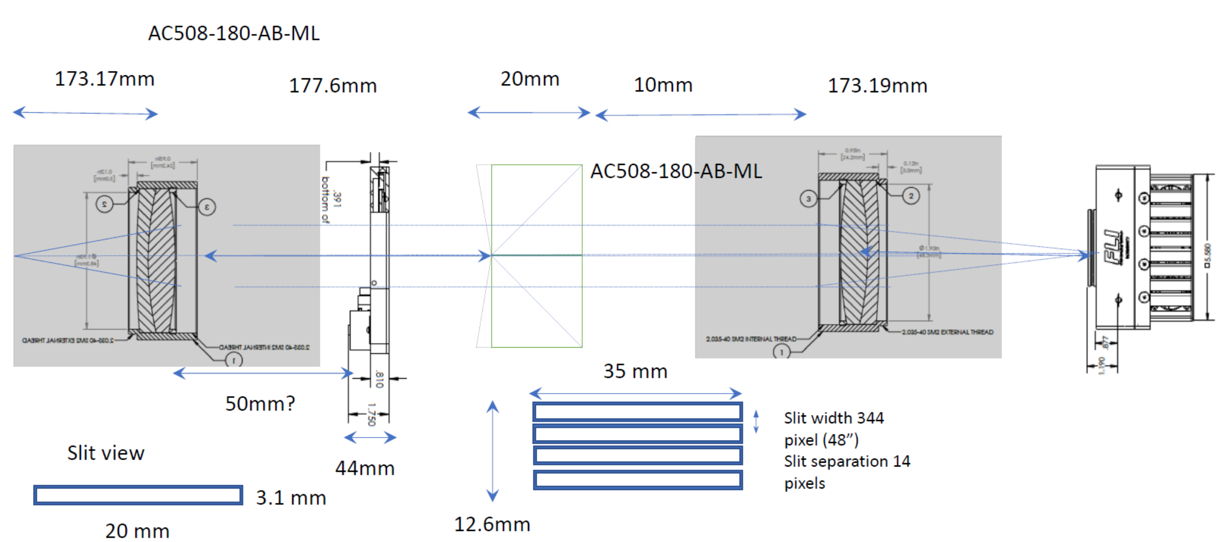

Figure 25: The NEOPol polarimeter layout, from left to right: incoming beam from the telescope 1. filed mask, 2. two inches achromatic doublet lens, 3. FLI CFW1-5 filter wheel, 4. Wedged double Wollaston, 5. the second two inches achromatic doublet lens, 6. FLI ProLine PL 16803 camera. The field mask slit has a dimension of 3.1 mm and 35 mm.

The NEOPol polarimeter is based on a Wedged double Wollaston configuration and its optical design layout is based on an initial optical arrangement to produce an unvignetted field of view (FOV) of 48” x 300” similar to the ToPol design [12]. The instrument is designed in such a way that it is a standalone device with two connectors: mains power and Ethernet. All devices that are needed to operate the polarimeter are integrated within the housing. The approximate external dimensions of the instruments are 680 x 325 x 220 mm.

The Data Processing Chain (DPC) automates the polarimetric data reduction from NEOPol instrument. The automation allows for future extension to similar new or existing instruments. The service will be accessible via web user interface (UI) and a command line interface (CLI). The full DPC will estimate asteroid diameter and geometric albedo from available data. The desktop user interface for the device will allow for image acquisition from the device via Ethernet (cable or wireless connection) and monitor available sensory data. The desktop UI will be used to acquire test data and DPC will be used on test data sets from real observations or synthetic data as a backup solution to demonstrate the fulfilment of the objectives. The DPC processing steps are the following:

1. Pre-processing (i.e., bias/dark/flat correction).
2. Processing (which yields photometric and astrometric measurements).
3. Polarimetric data analysis (which outputs polarimetric data into Polarimetric Database).
4. Absolute magnitude calculation.
5. Asteroid type / geometric albedo calculation.
6. Asteroid diameter calculation.

Steps 1 and 2 will utilize the already existing Astrometry24.NET (A24N) tool developed for ESA by Sybilla Technologies and Cilium Engineering (see [15] for details.) The DPC will be developed and tested on existing data gathered from the literature and/or available internally to the project team.

In order to allow for efficient management of devices included in NEOPol, a graphical desktop application has been designed. It allows the user to fully utilize the functionality of controllers in a user-friendly manner.

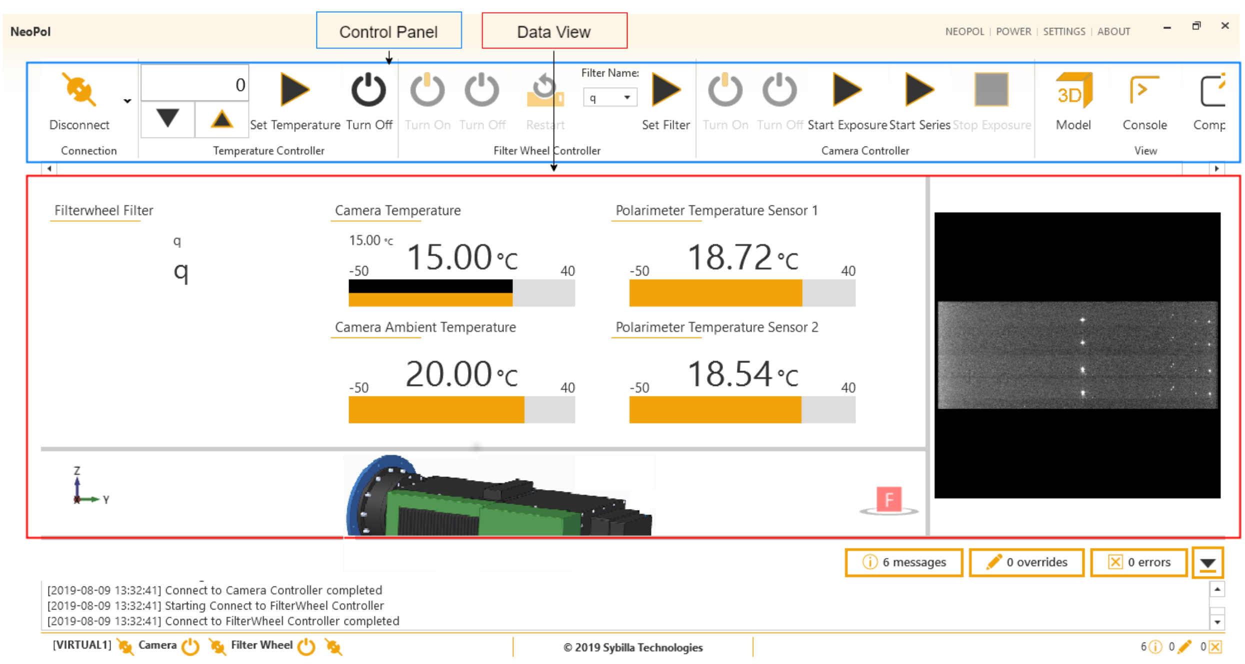

Figure 26:. The overall structure of the NEOPol graphical user interface.

The overall structure of the user interface has been divided into two main parts: one allowing to interact with devices (Control Panel) and one displaying the model view and output data (Data View). In both parts, functionalities have been grouped into individual sections to ensure the convenience in finding specific commands. Figure 26 presents the overall structure of graphical user interface. Both parts have been highlighted in different colors.

The NEOPol project will reach its Critical Design Review in Nov 2019. The instrument will be tested in Gdynia, Poland at the Panoptes-1AB 0.5m Planewave telescope belonging to the Baltic Institute of Technology. Subsequently, it will be relocated to the Observatorio del Teide in Tenerife, Spain, to be tested on the ESA Optical Ground Station 1.0m telescope [16]. Once commissioned, the system will be a unique asset to NEO studies providing an efficient way of polarimetric data acquisition and analysis, with the dedicated DPC adaptable to other similar instruments.

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