EUROPEAN EXPERT CENTRE FOR SPACE SAFETY PROVIDING SERVICES AND SUPPORT FOR SPACE SURVEILLANCE AND TRAFFIC MANAGEMENT

Thomas Schildknecht[(1)*], Peter Pessev [(1)], Palash Patole [(1)], Julian Rodriguez [(1)], Tim Flohrer[(2)], Beatriz Jilete [(2)], Emiliano Cordelli [(2)]

[(1)] Astronomical Institute University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland
[(2)] ESA ESOC, Robert-Bosch-Strasse 5, 64293 Darmstadt, Germany
**Corresponding author, email: thomas.schildknecht@aiub.unibe.ch*

ABSTRACT

Developed within ESA's SSA and Space Safety Programme (S2P), the Expert Centre for Space Safety provides subject matter expertise and operational services to coordinate SST data acquisition by a multitude of diverse sensors. It supports a variety of applications including tasked tracking, survey, and characterization observations by means of passive optical, satellite laser ranging (SLR), and radar techniques. A core service consists in the validation and qualification of sensors for the mentioned applications. The service includes technical support to sensor operators by experts to achieve compliance with data calibration and quality, as well as data formatting requirements. All formats and interfaces used by the Expert Centre are based on international standards and the data quality requirements are derived by the user community.

Coordinating observation campaigns for customers, in particular ESA, is another important service offered by the Centre. Such campaigns may include very heterogeneous types of sensors operated by commercial companies, academia, government, and inter-governmental institutions. The Expert Centre takes care of the sensor planning, the data quality control, calibration and reformatting of the data if necessary, as well as the monitoring of key performance indices defined in service level agreements.

In terms of object characterization, the Expert Centre focuses in particular on establishing and maintaining a catalogue of attitude information by fusing observations from different techniques, such as light curves, SLR and radar measurements.

The paper will illustrate the different services and operational capabilities with examples of sensor qualifications and extensive survey, tracking and characterization observation campaigns which involved more than a dozen optical, SLR and radar sensors.

The Expert Centre is hosted and operated by the Astronomical Institute of the University of Bern, Switzerland (AIUB) and may serve as a reference for future national expert centres and site-specific deployments within ESA.

1 INTRODUCTION

Some years ago ESA was starting an activity to set up and deploy a first version of an Expert Coordination Centre in the context of its Space Situational Awareness Programme. The center should serve as the focal point for the interfacing with a multitude of optical sensors and assets. These sensors should include optical passive telescopes and laser ranging sensors capable to measure ranges of objects which are not equipped with laser retroreflectors, also called non-cooperative targets. One of its prime task is to organize coordinated observation campaigns with a set of heterogeneous sensors and to provide calibrated and validated measurement data in well-defined standardized formats to ESA. Consequently, a strong technological focus is put on the complex networking and integration of a heterogeneous sensor network. The Expert Centre should thus act as single interface for user request and product delivery for the customer. Main functions were defined to address both, support and operational, tasks:

- Operations
  - Coordination of sensors for tracking, surveillance, or physical characterization (through ICDs) with the customer (service function, data processing function and data acquisition function),
  - Establishing and monitoring of Service Level Agreements with sensors, i.e. harmonized and comprehensive management and monitoring of availability, timeliness, and performance,
  - Routine and ad-hoc calibration of sensors.

- Support
  - Evaluation and qualification of sensors,
  - Definition of data processing schemes, techniques, and interfaces,
  - Evaluation of new techniques (hardware and software),
  - Research and development and collection and provision of expert support, e.g. support in interfacing with external technical entities at national and international level.

Proc. 2nd NEO and Debris Detection Conference, Darmstadt, Germany, 24-26 January 2023, published by the ESA Space Safety Programme Office
Ed. T. Flohrer, R. Moissl, F. Schmitz (http://conference.sdo.esoc.esa.int, February 2023)

Over the years the Expert Centre was further developed and new functionalities and services were established. The expert Centre is currently hosted and operated by the Astronomical Institute of the University of Bern (AIUB), Switzerland.

2 CAPABILITIES AND SERVICES

The Expert Centre for Space Safety, addressing optical passive, laser ranging, and radar observations, is providing services to a variety of users (see Figure 1). These include ESA acting as anchor customer, sensor operators, commercial partners, research and academic institutions and national expert centres. The services can be grouped into observation services, services for sensor operators, general services ("others" in Figure 1):

- Sensor services consisting of
  - validation and qualification service,
  - sensor-to-sensor data exchange service,
  - data calibration service.
- Observation services, including
  - astrometric survey and follow-up observations,
  - photometry observations,
  - conjunction events observation support,
  - re-entry event observation support.
- General services covering
  - attitude catalogue service,
  - technical expertise,
  - research and development,
  - support in standardization.

In order to provide the observation services, the Expert Centre established an extensive network of federated sensors for all observation techniques. Service level agreements with most of these sensors allow for a flexible assignment of these means according to the requirements of the user.

Figure 1. Space Safety Expert Centre users, services and network of sensors

At the technical level the Expert Centre is making use of a series of subsystems:

- I/O subsystem that enclose the heterogeneous interfaces with a customer backend segment and interfaces with individual passive optical, SLR and radar sensors.

- Planning and coordination subsystem that allows the Expert Centre to coordinate ad-hoc validation, qualification and calibration campaigns, as well as all type of campaigns required for the observation services.
- Data format conversion subsystem, that allows to provide all data and services in standardized formats (e.g. CCSDS formats).
- Data calibration and evaluation subsystem supporting the calibration and evaluation of sensor data.
- Sensor validation and qualification subsystem to perform standardized validation and qualification campaigns.
- SLA monitoring subsystem to assess sensor compliance with SLA.
- Sensor status subsystem receiving and sending the status of sensors.

In the following, we present a brief description of the main services.

3 VALIDATION AND QUALIFICATION OF SENSORS

Optical passive and active laser sensors are qualified in two steps. In a first step they are tasked to provide tracking observations of a few calibration objects in a well-defined format (e.g., CCSDS Tracking Data Messages). The purpose of this step is to establish the communication interfaces, to ensure that the sensor is able to provide tracking data of the tasked objects, and to validate that the formats are correctly implemented.

The qualification shall certify that a sensor may reliably provide data of specific objects in defined orbital regime(s), respecting defined quality criteria. In the following we describe, as an example, the procedure for passive optical sensors. A qualification campaign for this type of sensors consists of 3 full observation nights. Within each night the sensor is tasked to provide observations of 12 calibration objects and 4 typical objects in the orbital regime for which the sensor shall be qualified. The tasking is done in quarter-night batches. Calibration objects are objects with fiducial orbits, e.g., GNSS satellites, where high accuracy orbits are available at AIUB.

Often data provided by sensors at the beginning of a qualification campaign do not fully comply with format and coordinate system requirements, or show an epoch offset exceeding the qualification requirement. For such cases subject matter experts from the Expert Centre will support the sensor operators to resolve such issues and improve the data quality. Figure 2 shows the astrometric residuals of optical observations from a sensor qualification campaign. The residuals are represented in an along-track/cross-track reference system scaled with the distance of the calibration object (GNSS satellite). In Figure 2 there is clear systematics with offsets of up to 1500m corresponding to about 15 arcseconds at the celestial sphere. After correcting for a wrong reference system (transformation from a heliocentric into a geocentric reference system) and for an epoch offset of 100ms the results are significantly improved. The rms of the astrometric position was estimated at about 0.5 arcseconds (Figure 3).

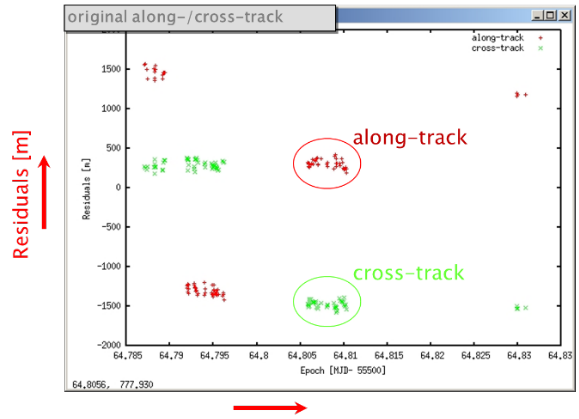

Figure 2. Astrometric residuals of optical observations from a sensor qualification campaign

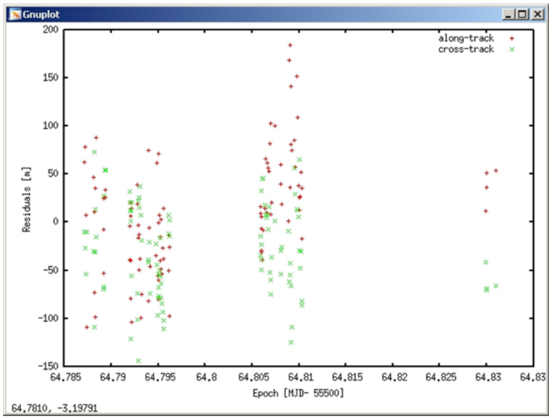

Figure 3. Astrometric residuals after transformation from a heliocentric into a geocentric reference system and after applying a 100ms epoch offset

Successful qualification requires a set of key performance indices (KPI) to be above an agreed thresholds (see Table 1). Figure 5 shows a graphical representation of the KPIs from a qualification campaign of a passive optical sensor.

Table 1. Key performance indices for passive optical sensor qualification.

Efficiency	number of objects successfully tracked and processed with respect to tasked objects
Latency	time span between observation and data delivery
Epoch offset	epoch offset w.r.t. UTC as derived from processing the calibration objects (GNSS s/c)

Epoch offset stability	stability of the epoch offset within one night and from night to night
Astrometric accuracy (after epoch offset correction)	astrometric accuracy as derived from processing the calibration objects (GNSS s/c)
Miss-correlation	observations which do not belong to the tasked object

Once a sensor successfully passed the Expert Centre validation and qualification procedure it becomes a certified sensor and is eligible to provide reliable SST data in observation campaigns coordinated by the Expert Centre (usually covered by an SLA).

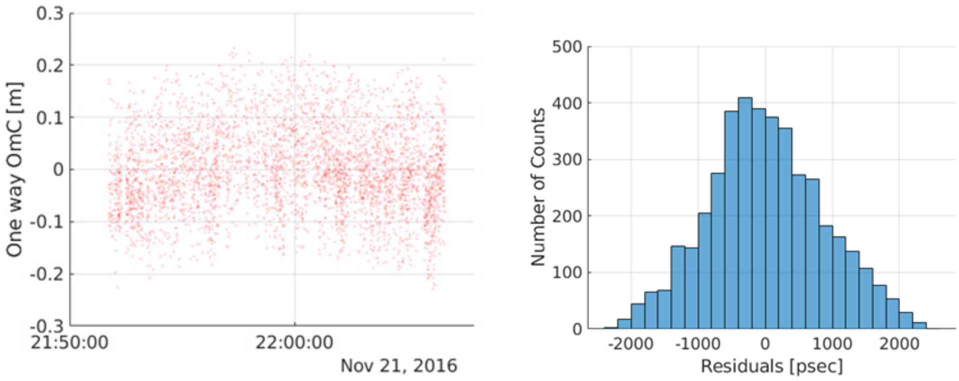

Figure 4. Range residuals of a space debris SLR system for the geodetic satellite LAGEOS after time and range bias correction; left: residuals as a function of time, right: histogram of residuals

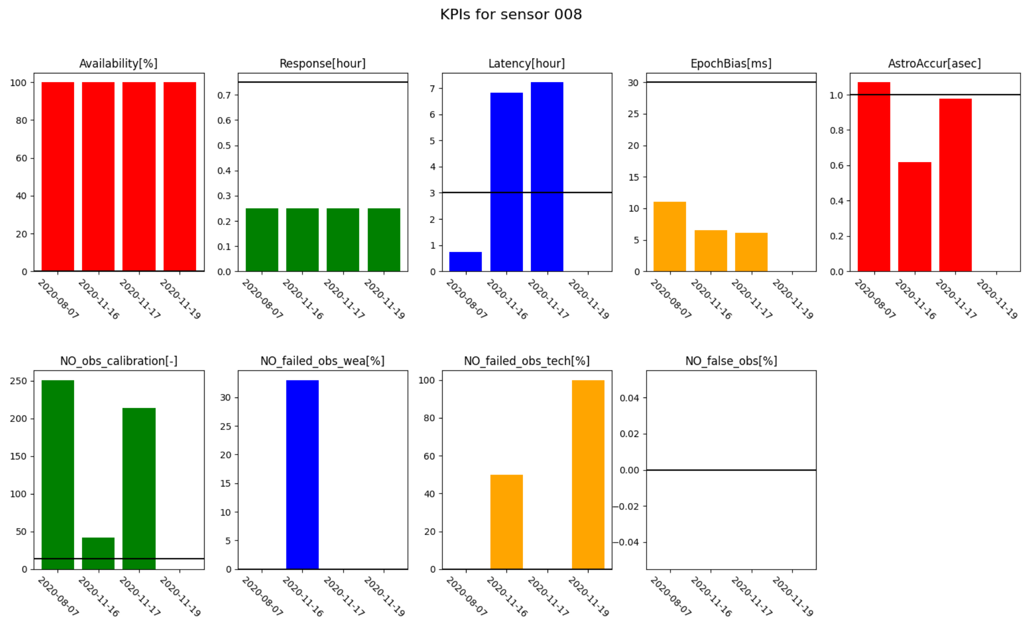

Figure 5. Example of key performance indices from a passive optical sensor qualification campaignSimilar KPIs are used for the qualification of a laser ranging sensors. In these cases, geodetic SLR satellites serve as calibration targets. The reference orbits of these objects are accurate to a few decimeters. Figure 4 shows the residuals of a space debris SLR system for the geodetic satellite LAGEOS after time and range bias correction.

4 DATA ACQUISITION CAMPAIGNS

Coordinating observation campaigns for customers, in particular ESA, is another important service offered by the Expert Centre. Such campaigns may include very heterogeneous types of passive optical, laser ranging and radar sensors operated by commercial companies, academia, government, and inter-governmental institutions.

Bases on the high-level customer requirements, the Expert Centre takes care of the sensor planning, the data quality control, calibration and reformatting of the data if necessary, as well as the monitoring of KPIs. All communication and data exchange with the customer are done via standardized interfaces. For observation campaigns, service level agreements are established with all participating sensors.
The Expert Center organized several extensive survey, tracking and characterization observation campaigns which involved more than a dozen optical, SLR and radar sensors (Figure 6). Since August 2020 more than 500 nights of data has been acquired with17 individual sensors (passive optical, debris SLR, and tracking radars, see Figure 7). Sensor-specific monitoring of the data quality during such campaigns is crucial. Figure 8 shows an example where the epoch offset and the astrometric accuracy of a sensor could be significantly improved over time.

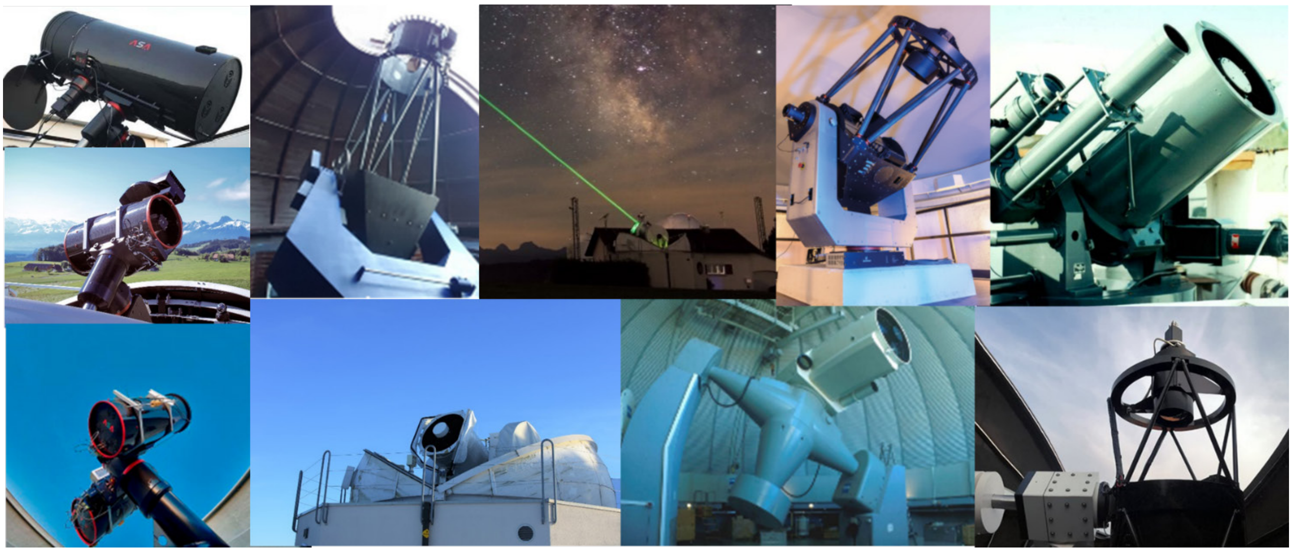

Figure 6. Example of sensors participating in one of the observation campaigns; clockwise from top left: Airbus-RT (Spain) and AIUB ZimSMART (Zimmerwald Switzerland), AGO 70 telescope (Modra, Slovakia), AIUB SLR (Zimmerwald, Switzerland), AIUB ZimMAIN (Zimmerwald Switzerland), SLR system Boroviec (Boroviec, Poland), ESA TBT telescope (La Silla, Chile), ESA OGS telescope (Tenerife, Spain), AIUB ZIMLAT (Zimmerwald, Switzerland), AIUB ZimTWIN (Zimmerwald, Switzerland).

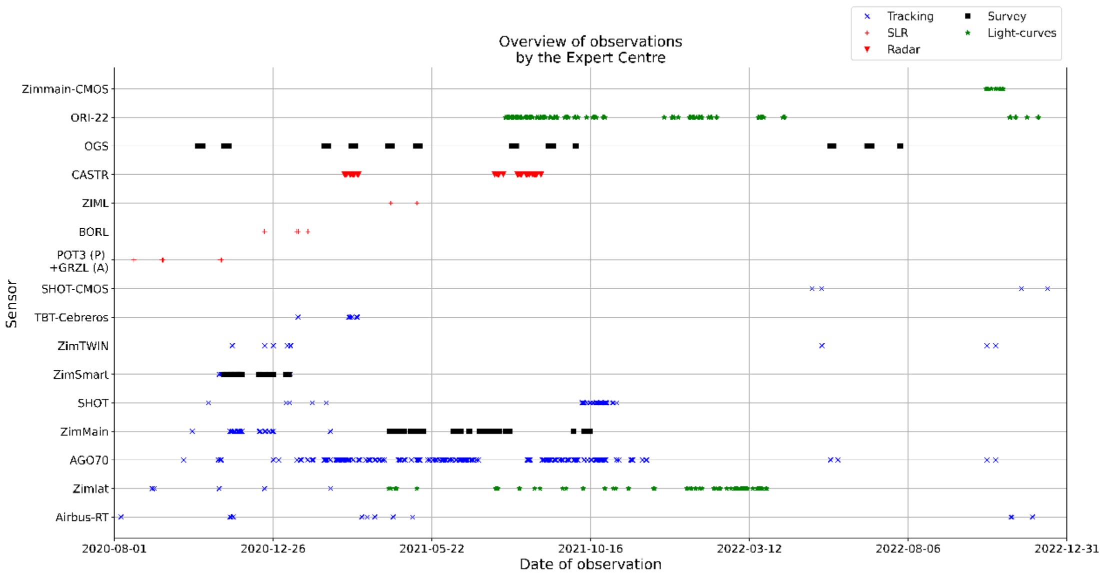

Figure 7. Overview on the data acquisition campaigns handled by the Expert Centre; symbols indicate individual observation nights per sensor

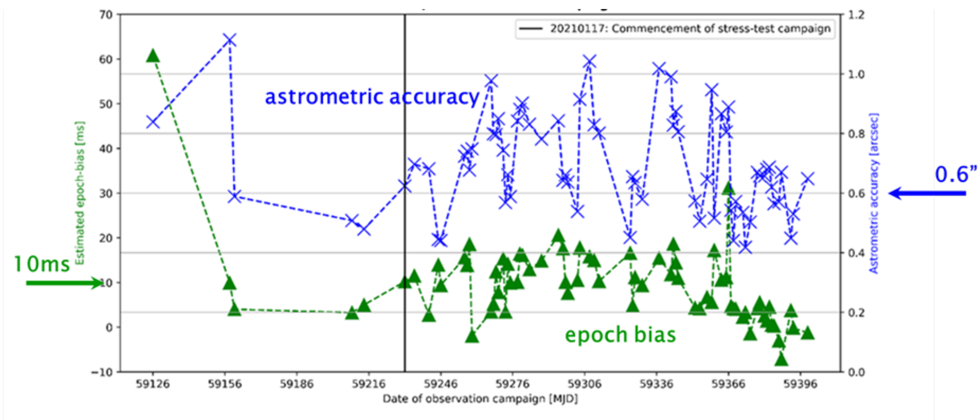

Figure 8. Example of results from a data acquisition campaign with a passive optical sensor where the epoch offset (“epoch bias”, green) and the astrometric accuracy (blue) of a sensor could be significantly improved over time

5 ATTITUDE INFORMATION SERVICE

The Expert Centre is currently extending its capabilities to provide support for attitude-related analysis. In this context an attitude information catalogue is built-up and maintained. Attitude information is derived primarily from optical light curves, but laser ranging and radar data may be fused with optical data to derive attitude-related information. This service will include the planning, scheduling, acquisition, and processing of the basic observation data needed for attitude estimation. Algorithms are developed to automatically categorize targets according to tumbling rates using simple categories like “stabilized”, “slow rotator”, “fast rotator”, etc., including the estimation of the rotation rates. Figure 9 provides an example of the basic observation data for attitude information.

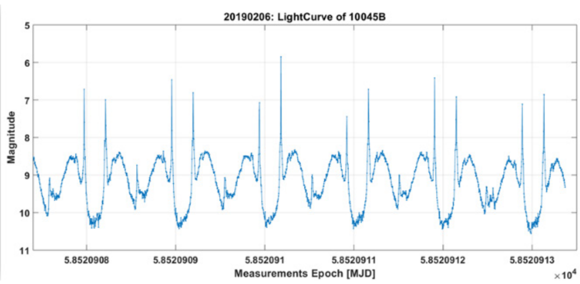

Figure 9. Example of a light curve of a tumbling upper stage

6 SUPPORT TO STANDARDIZATION

Data format and standards became absolutely central for the complex networking and integration of a heterogeneous sensor network. Similarly, standards are essential for the communication with the customer to ensure that this interface is agnostic to various customer backends. The Expert Centre is further addressing the development of data exchange standards and networking concepts in an international context. It is in particular supporting the review of standards in the CCSDS, ECSS, CEN/CENELEC, and other bodies.

7 SERVICES UNDER DEVELOPMENT

The Expert Centre is currently developing and implementing the capacity to ingest conjunction data messages (CDM) to trigger ad-hoc observation requests for high risk conjunction events in LEO and GEO orbits. The service will include the possibility to improve the orbit prior to the provision of the orbital information back to the customer.

Similarly, the capacity to process reentry data messages (RDM) to trigger corresponding observation requests for imminent re-entry events is developed and implemented. This service is pending full validation with a real reentry, subject to visibility of the reentry passes from the sensors the Expert Centre has service agreements with.

8 SUBJECT-MATTER EXPERTISE AND R&D ACTIVITIES

Thanks to its pool of experts, the Expert Centre is prepared to provide subject-matter expertise in various domains. Using AIUB’s Bernese software and CODE orbit products, the Expert Centre validated range data from ESA’s IZN-1 SLR station in Tenerife and determined the uncertainties and biases of these measurements. Range residuals of GLONASS measurements with respect to global orbit solutions of the Center of Orbits determination in Europe (CODE, hosted at AIUB) are given in Figure 10.

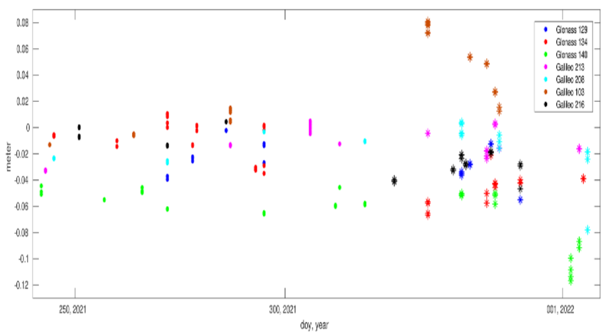

Figure 10. Range residuals of the ESA SLR station IZN-1 as determined in the context of a range bias analysis using AIUB's Bernese software and CODE orbit products

The Expert Centre performs several research and developments activities, in particular in the domain of space debris SLR during daytime and the fusion of range and photometric light curves for attitude determination. The result of a new algorithm for the discrimination of SLR returns from a space debris object from noise events is shown in Figure 11.

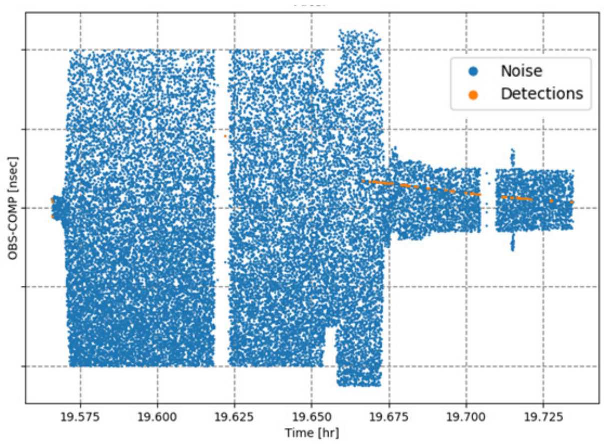

Figure 11. Discrimination of SLR returns from a space debris object (red) from noise events (blue)

9 SUMMARY

The Expert Centre for Space Safety, established and hosted at the Astronomical Institute of the University of Bern (AIUB), Switzerland and under test operation as part of ESA's Space Safety Programme, provides a multitude of services in support of space surveillance and space traffic management. The coordinated data acquisition by a wide range of diverse sensors is at the core of its activities. It supports a variety of applications including tasked tracking, survey, and characterization observations by means of passive optical, laser ranging, and radar techniques.

The Expert Centre provides extensive validation and qualification services for the mentioned applications and sensor types in order to certify them for future observation campaigns. Subject matter experts from the Expert Centre support the sensor operators in this process.

Another core service of the Expert Centre consists of coordinating observation campaigns for customers, in particular ESA. Several extensive survey, tracking and characterization observation campaigns, which involved more than a dozen optical, SLR and radar sensors, were already performed.

All core services are fully operational and further services are currently developed within an ongoing activities of the ESA Space Safety Programme.

A test service to provide support to attitude estimation, including the build-up and maintenance of an attitude data base, will be available soon. The capacity to ingest conjunction data messages and reentry data messages to trigger corresponding observation requests is currently developed and validated.

These additional services will be critical components in support of safe and sustainable operations in space.