SPACE SURVEILLANCE AND TRACKING IN ESA'S SSA PROGRAMME

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ABSTRACT

Understanding the space environment, especially space weather, near-Earth objects, space debris, and being able to forecast related events, has become essential to protect the critical infrastructure in space. ESA, recognising that need, started in 2009 its Space Situational Awareness Programme with three segments Space Weather, Near Earth Objects and Space Surveillance and Tracking . Today, 19 member states of ESA participate in this optional programme of the Agency. We report on the substantial progress in the frame programme, with focus on the Space Surveillance and Tracking domain developing applications and new technologies, and report on the plans for the new programme period 3 covering the years 2017-2020.

1 INTRODUCTION

Today, space-based systems for navigation, communication, Earth observation, meteorology and many other applications are indispensable for services critical to Europe's economies, and this dependency is constantly growing. The space environment poses, however, a risk to space-based systems, as well as to the population and infrastructure on the ground. Understanding the space environment, especially space weather, near-Earth objects, space debris, and being able to forecast related events has become essential to protect the critical infrastructure. The growing number of smaller satellites and plans for placing large constellations in orbit further drive the need for timely and actionable information.

Since 2009 ESA, recognising that need, has been undertaking an Space Situational Awareness (SSA) Programme with three segments: Space Weather (SWE), Near Earth Objects (NEO) and Space Surveillance and Tracking (SST). The awarded high-added-value contracts aimed at the design of the overall SSA architecture, at developing the required systems and technology and at providing precursor services. The development of the technologies for detection, cataloguing and follow-up of space objects, and of the derived applications for conjunction event prediction, re-entry predictions, and fragmentation event detection is considered as the first important step towards an European SST capability.

ESA is focussing on research and development, supporting national initiatives, and staying complementary with other European approaches in SST in the new period 3 of the SSA programme (2017-2020). From on-going national activities in Europe, a demand for larger, cross-national SST components and related technology developments is expected to ensure interoperability of systems. Examples of related activities are space-based SST sensors, processing software facilitating data exchange mechanisms, and common data processing techniques and formats. Through the SSA programme ESA's expertise will be exploited in supporting the research, development, and coordination of space-related technologies in a multinational environment, and in assessing and maturing further the relevant emerging new technologies in close coordination with the appropriate technology domains.

2 SSA PROGRAMME OVERVIEW

The SSA Programme is being implemented as an optional ESA programme with financial participation by 19 Member States. SSA activities have been funded at a total of approximately 200M€. The current period of the programme is funded at 95M€ for the years 2017–2020. The SSA programme is providing strong benefits to European industry. For example, during its first two periods, over 100 contracts were issued to industry for SSA-related work.

The following Member States are participating in current period, 2017-2020, of SSA: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland, and the United Kingdom.

The SSA Programme is managed through a Programme Office that is based at ESA's ESOC Establishment, while technology research and development, project planning and industrial contracting are being conducted by teams located across the Agency, and at European industrial partners.

The SSA programme is focusing on three main areas, SWE, NEO, and SST, which are organised in segments of the programme.

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2.1 SWE Segment

Space weather addresses all aspects on monitoring conditions at the Sun and in the solar wind, and in the Earth's magnetosphere, ionosphere and thermosphere, that can affect spaceborne and ground-based infrastructure or endanger human life or health. In order to achieve reliable space weather services, constant monitoring of the space environment from a range of vantage points is needed, together with timely dissemination of reliable data to those needing the information in industry, government and research institutes. The raw measurements must be fed into advanced computational models and tools in order to give near-real-time information, advanced warnings and forecasts of upcoming space weather conditions that may affect a diverse range of systems and activities.

The SWE Segment is building on the vast European expertise and established assets of observations, results, models, and products to develop a federated space-weather service-provision concept, avoiding duplication and ensuring that existing assets and resources play a key role in Europe's new SSA system.

ESA's SSA space weather services are centred around ESA's Space Weather Coordination Centre (SSCC) located at the Space Pole in Belgium providing Europe's first Space Weather Helpdesk, and a federated network of Expert Service Centres (ESCs) across Europe. This network also includes the SWE Data Centre at ESA's Redu Centre complemented by discipline-specific Data Centres within SSA Member States.

2.2 NEO Segment

NEOs are asteroids or comets with sizes ranging from a few meters to tens of kilometres that orbit the Sun and whose orbital paths come close to that of the Earth. Of more than 700,000 known asteroids in our Solar System, over 16,000 are known to be NEOs. To date, more than 90% of objects with diameters larger than 1 km have been discovered, but this figure drops to only 10% when considering 100 m-sized objects, any one of which would be many times more destructive if they hit Earth than the Tunguska or Chelyabinsk events.

The goals of the NEO Segment are to expand the knowledge of the current and future position of NEOs relative to Earth, to estimate the likelihood of Earth impacts, to assess the consequences of any possible impact, and to develop NEO deflection methods. By coordinating Europe's role in the global asteroid hunt through syndicating and federating Europe's current observation capabilities and data sources, the NEO Segment actively observes NEOs, predicts their orbits, produces impact warnings when necessary and is involved in developing mitigation measures. These work is accompanied by developing new sky-survey technologies, such as automated telescopes, together with a more efficient data and information handling network.

2.3 SST Segment

Space debris is now one of the principle threats to our infrastructure in orbit. It is estimated from ESA's MASTER model [1] that more than 750,000 objects larger than 1 cm are in Earth orbit with the potential to damage or destroy intact satellites, creating yet more fragments.

Space Surveillance and Tracking (SST) comprises technologies to detect, catalogue and predict the objects orbiting the Earth, and the derived applications. The recent years have shown constantly growing needs for timely and accurate SST data, especially for collision avoidance as part of operating spacecraft, and for assessing re-entry events. Despite of recent progress in implementing space debris mitigation measures [2] the frequency of in-orbit fragmentation events is still significant. Ref [3] finds that while considering only those events which resulted in more than 50% of the fragments having an orbital lifetime greater than 20 years, one still obtains a yearly rate of about 3.4 breakups as the average of the last 10 years. SST provides the means to detect in-orbit fragmentations, and to share catalogued orbit information of the generated fragments.

Today, ESA and all European national space agencies and commercial operators depend on surveillance data from non-European (mainly US) sources.

It should be noted that in the ESA context, the exploitation of external surveillance data is outside the scope of the SSA program. Operational support to missions based on surveillance data is provided through services from ESA's Space Debris Office. ESA as operator of spacecraft has own needs for the protection of ESA assets, such as for ensuring a collision avoidance service [4], and re-entry prediction and assessment services [5] and to support spacecraft contingencies and special mission phases, such as Launch and Early Orbit Phases (LEOPs). For supporting the operations of own assets, a data-sharing agreement between USSTRATCOM and ESA was signed in 2014, allowing ESA's operations to be alerted in case of an identified risk of collision.

Beside the widely understood operational needs on SST data, the future will further show a growing need for SST data to support the evaluation of the effectiveness of mitigation guidelines, and as input to addressing regulatory issues. The recently launched dozens of small satellites per event, as well as the announcements of placing several large commercial constellations in orbit set two prominent and currently widely discussed examples. There will be further growing needs for establishing European independent SST data acquisition and processing capabilities.

As part of SSA, ESA is developing, demonstrating, and validating the SST technologies. ESA aims at providing the required research and technology development for an autonomous European SST capability supporting national initiatives, and staying complementary with other European approaches.

2.4 SSA Developments in the ESA Program

In this section we very briefly outline central development aspects in ESA's SSA programme since 2009. A starting point for the activities have been preparatory studies, such as an extensive study reported in [6]. Two independent architectural design studies based on the requirements of the European SST stakeholders have been conducted during the first two periods of the SSA Programme.

Preparatory Period 1 (2009–12)

The work concentrated on technology and system architecture tasks. Significant infrastructure was developed at ESA and partner facilities in several countries, such as the Space Weather Coordination Centre at Space Pole, Brussels, Belgium, the Space Weather Data Centre at the ESA Redu Centre, Belgium, the NEO Data Centre at ESA/ESRIN, Italy, the Space Surveillance and Tracking Data Centre at ESA/ESAC, Madrid, Spain, the SSA Centre at ESA/ESOC, Darmstadt, Germany, a monostatic test-bed radar system at Santorcaz, Spain, as well as a bistatic test-bed radar system in France. Further, the initial design of the SSA FlyEye automated telescope to enable full-sky NEO surveys was completed.

Period 2 (2013–16)

The system development work continued with the goal of progressively prototyping, developing, testing and validating the main components of a future European SSA system. This was achieved through several activities, such as in SWE the expansion of data and coordination centres, development of sensors, applications and user interfaces, provision of precursor services, studying the deployment of hosted payloads, expanding the utilisation of data from satellites in orbit, networking and integrating existing European space-weather infrastructure through the creation of a series of Expert Service Centres (ESCs), procurement of SWE instruments having an identified flight opportunity, exploitation of the Proba-2 mission, and studies of an enhanced space weather monitoring system including sensors orbiting at various Lagrange points. In NEO efforts for observation campaigns increased and automatic tasking and data-processing functions were developed further, the FlyEye wide-field-of-view telescope development continued, and studies related to asteroid impact mitigation have been conducted. Further development of SST systems addressed the test and validation of radar detection techniques, SST software tools, applications and data systems, and increased the research and development in satellite laser ranging and optical surveillance techniques.

Planned developments in Period 3 (2017–20)

The currently starting and planned activities place increased emphasis on developing SWE and NEO services, while research, development and validation activities continue in the SST domain.

The SWE activities aim at further developing and validating the provision of services for all user domains identified in the SWE Customer Requirements Document with priorities based on consultation with the users and stakeholders and following the federated service approach initiated in Periods 1 and 2. SWE will focus on ensuring the availability of space-based measurement data required by the SWE services, and on developing an operational European SWE measurement capability, complementary and in collaboration with international partner efforts, where possible, to ensure long-term sustainability of the required measurement systems. Three main regions in space for SWE measurements are the Near-Earth space, the Sun-Earth line (L1), and away from the Sun-Earth line (L5). SWE data are complemented by ground-based measurements.

The NEO segment will be active in all NEO-related areas but will concentrate on wide surveys of smaller objects and on performing follow-up observations, orbit predictions and impact risk assessments for all known NEOs. It will support, in international coordination, the information exchange on NEOs and potential mitigation measures by civil protection measures or NEO deflection space missions, and the further developments (Fly-Eye) and enhancements of existing NEO sensors.

The goals of the SST area are addressed in the next section in a wider scope.

3 SST GOALS IN THE PROGRAMME PERIOD 3

The core activity of any SST system is a building up and maintaining a data catalogue containing information on all objects that have been detected in orbit. To achieve this the catalogue is regularly updated (maintained) by processed measurement data. Subsequently, applications using the catalogue data can be provided, such as to automatically assess the probability of collisions between the thousands of tracked objects and operational satellites and then, when necessary, issue warnings to satellite operators. Another possible SST application addresses the detection and decay prediction of larger pieces of space debris – typically non-functioning satellites or upper stages – that may re-enter the atmosphere and possibly endanger people or infrastructure on ground. The catalogue can also be used to detect when fragmentations occur in orbit. SST catalogues also provide derived functions, such as to help operators of small satellites with lean ground segments to determine their orbital location, and by that to exploit lower-cost 'cubesats' to conduct valuable research. SST data is also essential to validate the effectiveness and level of compliance with space debris mitigation guidelines [2].

A comprehensive status overview on the current situation and the prospective post-Period 3 achievements compared to the ESA's SSA Customer Requirements Document (CRD) and the proposal for Period 3 activities to ESA's Council at Ministerial Level in December 2016 are shown in Fig. 1. Best progress so far can be reported on the application side and for some selected sensor technologies, while for the survey radars no roadmap is laid out, and the data centre processing is under integration during 2017. The development of a full-scale ground-based survey radar that meets the requirements is not covered during SSA Period 3, as priority is given at this stage to supporting the development or enhancement of national SST radar capabilities.

The subsequent sections detail the plans along a SST data stream: starting with sensor systems, followed by data processing aspects, and the derived applications also addressing data exchange formats and standards, and aspects of collaboration.

3.1 Sensors

Development of sensor technologies in the SST domain focusses on studying and specifying cross-national components at all technology readiness levels, and on the support to qualifying national sensors.

The first objective for the development of new sensor technologies is the further study and development of a space-based instrumentation for SST purposes. Basic studies from ESA General Studies Programm (GSP) have delivered a viable Phase A concept that uses a platform in a sun-synchronous dusk/dawn Low-Earth Orbit to scan the entire GEO daily. A passive fix-mounted telescope with an aperture of about 20 cm is sufficient for SST tasks. In a different mode, the same sensor can significantly contribute to improving the statistical knowledge on the sub-catalogue small-size space debris population in LEO. That consolidated concept is now being studied further with support of the technology development programmes of ESA. In Period 3, a credible mission design and an engineering model of the sensor for a space-based SST component, either as a demonstrator mission or as a hosted payload on an Earth observation mission, will be developed. Building and operating such a mission can be carried out in collaboration with national entities

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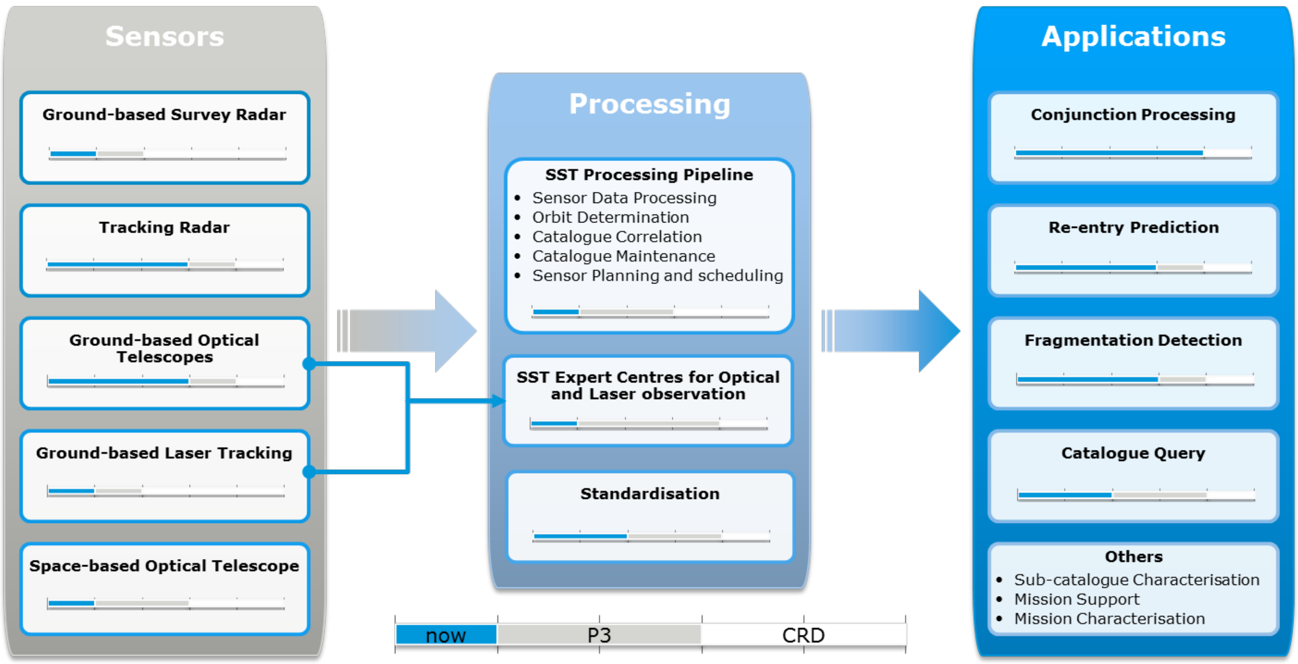

Figure 1. Status of the SST segment's activities related to the Customer Requirement Document (CRD), and the original goals for achievements from the programme period 3, as per 2016.

The enhancement and maintenance of telescopes, laser ranging systems, and radar sensors (both national and ESA-owned), are further objectives. Research and development activities are foreseen for surveillance and tracking radars, optical sensors and the emerging laser tracking of non-cooperative objects (see, e.g., [7]). This will be supported by implementing technological enhancements to ESA's two breadboard radars. The modular design and the inherent scalability of the phased array design allow augmenting the field-of-regard, increasing the transmit power, and extending the receiver area. In all cases, the cross-national technology developments in SST will be fully complementary to national activities.

SST will participate in the deployment and use of ESA's two robotic Test-Bed Telescopes [8], the first one installed at Cebreros, Spain, the second one foreseen for an installation in Chile.

3.2 Data Processing Technologies

In order to save development costs and avoid diverging service outputs by national systems, it is of paramount importance for European SST that a community approach for a SST core software for data generation kernels and formats is defined and established. Such a SST core software approach will allow existing and developing national systems to deliver compatible results, facilitating the development of efficient data exchange mechanisms, and establishing common data processing techniques and formats, and address the need for unconstrained interoperability of systems. To be successful, the approach will require a software governance mechanism involving national stakeholders that will define their joint requirements together with ESA. The national approaches and data policies will remain fully transparent in the governance mechanism and will not be constrained.

The initial work for a community approach to SST core software developments will comprise the consolidation of Member State requirements, the identification of common requirements, studying licensing needs, detailing an governance and licensing approach, and starting the development. It is foreseen that the SST core software will cover the data processing, the planning and scheduling, and the application software developed by ESA as the initial kernel, plus contributions from the community.

Establishing the SST core software in Europe will generate more opportunities for industry, especially for SMEs (e.g. to customise the software for national needs). In parallel and in support of the planned SST core software preparation, the SST data processing chain will undergo an end-to-end functionality test and validation. This implies the further development and demonstration of efficient networking technologies for integration of a complex system in a coherent SST segment. Related data processing activities will address advanced processing techniques, data correlation and tracklet formation and association, orbit determination, and data fusion approaches with the acquisition of sufficient test data sets.

The further development of SST networking technologies will drive the establishment of expert centres in the domain. An effective data exchange with external sensors is promoting interoperability. Qualifying, evaluating and promoting SST observations for sensor upgrades and developments is a key aspect of establishing a European SST functionality, also supporting national activities. Support for sensor qualification and evaluation can be provided through a first deployed version of the SST Expert Centre. The Expert Centre will not only act as a node to support sensor tests, calibration, and validation, but will also establish a link with international forums and drive the development and evaluation of new technologies. The concept if further detailed in [9].

Along with the development of networking technologies, a bottom-up consolidation of the evolving SST topologies in a European context needs to be assessed. This can be achieved using the architecture performance analysis tools in SST that are now available to support member states in consolidating the European SST approach. The results obtained will be considered for researching on the improvement of the networking of assets, and as well on the optimal inclusion and support of space-based components and external sensors to European SST approaches.

3.3 Applications

In Period 3, the SST applications for collision avoidance, re-entry event prediction, fragmentation event detection and catalogue querying, as well as the various support tools for visualisation, system architecture analysis, and data conversion will be maintained and further integrated. Further validation is planned on the basis of available data.

The full implementation of new standardised message formats will be pursued as well, all in support of the SST core software activities.

3.4 Collaboration, Standards

The current SST landscape in Europe is developing dynamically and has taken a new direction with the implementation of the EU funded Space Surveillance and Tracking Support Framework.

Within this complex environment, ESA's SST work will continue its R&D activities supporting the development of European capabilities on sensor technologies, data processing, and will support activities related to SST standardisation (e.g. in the CCSDS), as well as will perform pre-operational test and validation activities. Opportunities will be sought to develop cooperation and coordinate activities with the EU.

On the international side the development of standards allowing data exchange and service interoperability will continue. A prominent example is the initiative for establishing a re-entry data message (RDM) in the CCSDS context. SST is widely adopting CCSDS formats for application input and output.

4 SUMMARY AND OUTLOOK

As an optional programme with financial participation by 19 Member States ESA executes an SSA programme funded at a total of approximately 200M€ since 2009. ESA follows a step-wise approach that will allow to adjust each subsequent step to the condition reached before and to the fast-developing needs of Member States and to reduce the potential risk on time, scope and financing as the Programme progresses.

In the programme period 3 (2017-2020) ESA continues reinforcing networking technologies and enhancing available SWE, NEO and SST ESA and national assets, as well as developing new ground- and space-based components.

The SST activities continue research and development on SST technologies (radars, telescopes, and laser ranging systems), to initiate the development of a space-based optical component, also for statistical sampling of small sized debris, to develop a community approach to SST core software for data processing in line with the established SST architecture, and to perform the pre-operational test and validation of sensor technologies and data processing.

The SST segment has received a growing support among the participating states, with 11 having declared their interest in Period 3.

Supporting the research, development, and coordination of space-related technologies in a multinational environment and acting as an architect of a system of systems perfectly exploits ESA's expertise. ESA has the means available to assess and mature towards a further exploitation in the SSA programme of all relevant emerging new technologies in close coordination with the appropriate technology domains.

In order to save development costs and avoid diverging service outputs by national systems, it is of paramount importance for European SST that a community approach for a SST software core for data generation kernels and formats is defined and established.

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