ESA's SSA Programme: Activities in Space Surveillance and Tracking

Tim Flohrer, Holger Krag
ESA Space Debris Office and support to the Space Situational Awareness Programme Office, ESA/ESOC, Robert-Bosch-Strasse 5, DE-64293 Darmstadt, Germany

ABSTRACT

Today, satellites and space-based systems are indispensable for the provision of critical services. Understanding and forecasting the space environment, especially space weather, near-Earth objects, and the population of space debris is needed to protect our space-based infrastructure. The rapidly growing number of smaller satellites and maturing plans for deploying large constellations of satellites further increase the need for reliable and timely information on the space object population.

Since 2009 the European Space Agency (ESA) has been undertaking an Space Situational Awareness (SSA) Program with three segments Space Weather (SWE), Near Earth Objects (NEO) and Space Surveillance and Tracking (SST). Period 3 of the program has been approved at the ESA Ministerial Council in December 2016 for a 3-year period starting 2017.

A total of 19 member states of ESA participate in the SSA program, of which 11 subscribed to the SST segment. In SST, 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 are considered as the first important steps towards an European SST capability. To achieve this goal, ESA is focusing on research and development, supporting national initiatives, and staying complementary with other European approaches in SST. It is expected that in Europe a demand for larger, cross-national SST components and technology developments arises to ensure interoperability of systems. Examples of planned activities are space-based SST sensors, processing software, facilitating data exchange mechanisms, and common data processing techniques and formats. With the activities of the SSA program ESA's expertise will be further exploited in supporting the research, development, and coordination of space-related technologies in a multinational environment, and in assessing and maturing the relevant emerging technologies.

In this report we give a brief outline on ESA's SSA Program status and plans of all three segments in Section 1. In Section 2 we detail the status and plans for activities in the program's SST domain. We focus on SST applications and developing new technologies.

1. ESA SSA PROGRAM

Modern economies use navigation, communication, Earth observation, meteorology and many other applications and derived services. All these are, often barely visible, relying on the uninterrupted availability of a space-based infrastructure. Gaining a better understanding the space environment, especially space weather, near-Earth objects, the population of space debris, and being able to forecast related risk events is essential to protect our critical infrastructure in space, and also on-ground. We observe that access to space is becoming affordable for more and new players. Both, the rapidly growing number of smaller satellites and related massive releases, as well as the maturing plans for deploying large constellations of satellites, further increase the need for reliable and timely information on the space object population.

ESA, recognizing 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) since 2009.

The SSA Programme is managed through a Programme Office that is based at ESA's ESOC Establishment. It is being implemented as an optional ESA programme with financial participation by 19 Member States. During its first two periods, over 100 contracts were issued to industry for SSA-related work. The current period is funded at 95M€ for the years 2017–2019. Over all three periods, SSA activities have been funded at a total of approximately 200M€. In the current period Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland, and the United Kingdom are participating, which allows entities of these countries to bid for industrial activities.

1.1 Space Weather (SWE)

This segment addresses all aspects on monitoring conditions at the Sun and in the solar wind, and in the Earth's magnetosphere, ionosphere and thermosphere. All those can affect spaceborne and ground-based infrastructure or even endanger human life or health. Reliable space weather services require a constant monitoring of the space environment from a range of vantage points, and the advanced computational models and tools. Equally important is the timely dissemination of near-real-time information, advanced warnings and forecasts of upcoming space weather conditions to users in industry, government and research institutes.

The vast European expertise and already established assets of observations, results, models, and products are used in a federated space-weather service-provision concept. This approach avoids duplication and ensures that existing assets and resources continue to 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. Further, the segment is connecting a federated network of Expert Service Centres (ESCs) across Europe, the SWE Data Centre at ESA's Redu Centre, and various discipline-specific Data Centres within SSA Member States.

1.2 Near-Earth Objects (NEO)

A total of 16,000 of the more than 700,000 known objects in our Solar System 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. More than 90% of these NEOs are known, if the diameter is larger than 1 km. Only 10% of the 100 m-sized objects are known and anyone of these would be more destructive than these causing the Tunguska or Chelyabinsk events.

The segment is expanding the knowledge of the current and future position of NEOs relative to Earth by actively observing NEOs and coordinating Europe's role in the global asteroid hunt through syndicating and federating Europe's current observation capabilities and data sources. New sky-survey technologies and efficient data and information handling networks are developed. Further, the segment predict orbits, produces impact warnings by estimating the likelihood of Earth impacts and assessing the consequences of any possible impact, and develops NEO deflection methods and mitigation measures.

1.3 Space Surveillance and Tracking (SST)

SST comprises technologies to detect, catalogue and predict the objects orbiting the Earth, and the derived applications. ESA is developing, demonstrating, and validating the related SST technologies. Complementarity with other parallel European approaches, and the research and technology development in support of national initiatives is ensured through the programme implementation.

We expect a rapidly growing need for SST data to support the evaluation of the effectiveness of mitigation guidelines [1], and as input to addressing regulatory issues. Small satellites are launched with increasing frequency in massive releases. There are several announcements of placing several large commercial constellations in orbit. Still, SST is needed to detect in-orbit fragmentations, and to share catalogued orbit information of the generated fragments. Ref [2] obtains a yearly rate of about 3.4 breakups as the average of the last 10 years. Considering also statistical data on sub-catalogue size space debris, ESA's MASTER model [3] estimates 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.

Already today, relying on timely and accurate SST catalogue data is reality in modern spacecraft operations, especially for collision avoidance and for assessing re-entry events. ESA and all European national space agencies and commercial operators depend on surveillance data from non-European (mainly US) sources.

At ESA 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 processes in place, 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 ESA 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.

1.4 ESA's SSA Programme Development and Status

In 2009 the programme started with a preparatory period, following previously completed feasibility studies of ESA, as, .e.g., reported in [6]. The preparatory work concentrated on technology and system architecture tasks. Following a to-down approach initiated by collected requirements of the European SST stakeholders the Mission, Customer, and System requirements for a full SSA capability have been derived. From two independent architectural design studies the matching system architectures were described and related costs were estimated.

In parallel, a significant infrastructure was developed at ESA and partner facilities in several countries. Examples are 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, and the SSA Centre at ESA/ESOC, Darmstadt, Germany. Key hardware developments include a monostatic breadboard radar system at Santorcaz, Spain [7], and a bistatic test-bed radar system in France [8]. A FlyEye automated telescope to enable full-sky NEO surveys has been designed [9].

During the Programme period 2 from 2013 to 2016 ESA and the industry teams prototyped and developed the main components of a future European SSA system. Testing and validating started. In SWE this was achieved through the expansion of data and coordination centres, the development of sensors, applications and user interfaces, and the provision of precursor services, especially via the networking and integrating of existing European space-weather infrastructure through the creation of a series of Expert Service Centres (ESCs). Further, SWE started the procurement of instruments having an identified flight opportunity, and exploited ESA's Proba-2 mission. Future plans for deployment of hosted payloads and enhancing the space weather monitoring system with sensors orbiting at various Lagrange points were consolidated. NEO increased the acquisition of observations, and the efforts for establishing automated tasking and data-processing functions. Concepts for asteroid impact mitigation were studied. The FlyEye wide-field-of-view telescope development continued. SST focused on the test and validation of radar detection techniques, the development of SST software tools, applications and data processing systems. New aspects were the research and development activities for satellite laser ranging to non-cooperative objects, and specific optical space surveillance techniques.

The Programme period 3 started 2017 following a decision at the ESA council at ministerial level in December 2016. Increased emphasis is on developing SWE and NEO services, while research, development and validation activities continue in the SST domain. SWE activities aim at further developing and validating the services for all identified user domains. The federated service approach will continue with service prioritization from consultations with the user community. In complementarity and in collaboration with international partner efforts an operational European SWE ground-based and space-based measurement capability will be further developed to ensure long-term sustainability of the required measurement systems. NEO will continue with activities in all NEO-related areas. Focus will be on conducting wide surveys and follow-up observations, orbit predictions and impact risk assessments. The international efforts on coordination and information exchange will be further supported, as well as studying mitigation measures and NEO deflection space missions. The Fly-Eye telescope development will continue. SST plans are addressed in the next section.

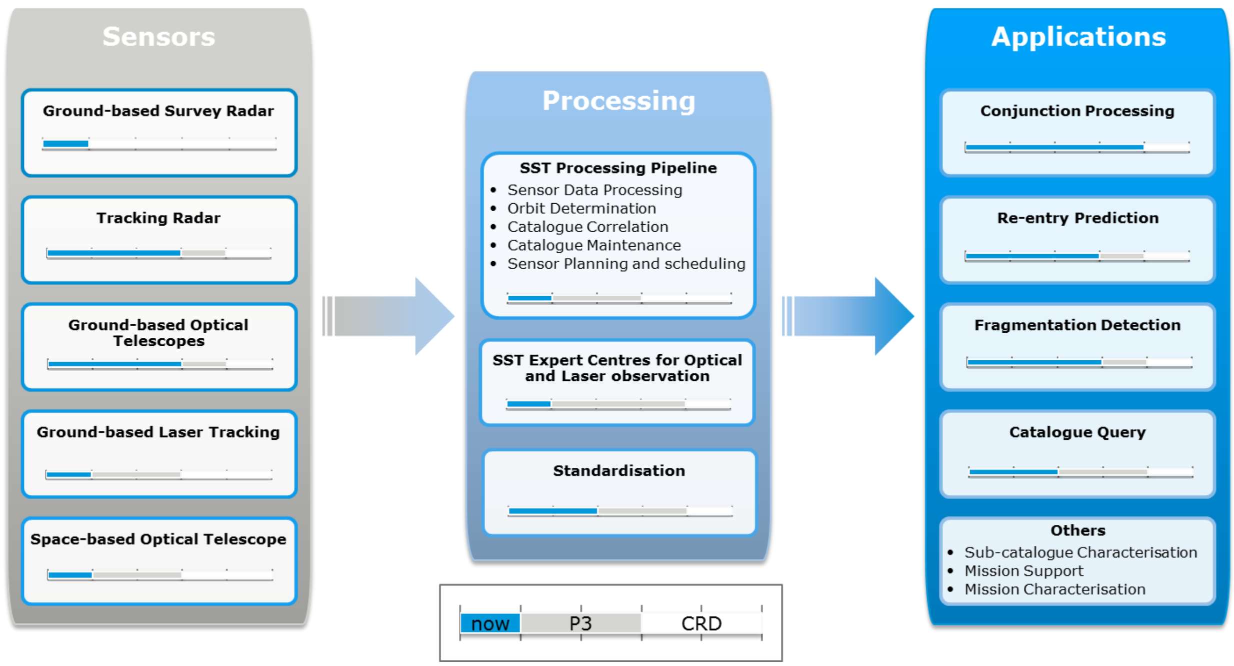

Fig. 1. Status of SST developments, plans for period 3 of the programme, and requirements in the CRD.

2. SST PLANS IN PROGRAM PERIOD 3

The plans in Programme period 3 for SST are detailed in this section. We follow the SST data stream: starting with sensor systems, followed by networking and data processing aspects, and the derived applications. Data exchange formats and standards, as well as collaboration are addressed separately.

We can compare the current status and planned achievements in the programme to the established ESA's SSA Customer Requirements Document (CRD). Figure 1 shows that 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 for the period 3.

2.1 SST Sensor activities

One new sensor technology for Europe that is studied is a space-based instrument for SST purposes. Basic studies conducted under the ESA General Studies Programme (GSP) have delivered a viable Phase A concept [10]. A platform in a sun-synchronous dusk/dawn Low-Earth Orbit that scans the entire GEO daily with passive fix-mounted telescope of about 20 cm aperture was found sufficient for supporting the SST tasks defined in the CRD. The mission concept is flexible for implementation through either a demonstrator, or a hosted payload on an Earth observation mission, both in collaboration with national entities. Further, that sensor design can significantly contribute to improving the statistical knowledge on the sub-catalogue small-size space debris population in LEO. With support of the technology development programmes of ESA the consolidated design from the GSP study is further detailed [11]. A refined mission design and an engineering model of the sensor for a space-based SST component is planned in period 3.

Ground-based telescopes, laser ranging systems, and radar sensors are subject to research and development activities (see, e.g., laser ranging developments [12-14], the use of ESA's two robotic Test-Bed Telescopes [15], or the monostatic and bistatic radar breadboard systems owned by ESA). It is an objective to continue supporting national sensor developments, especially for meeting cross-national technology needs at all technology readiness levels, and for qualifying national sensors.

2.2 Activities in sensor networking and SST data processing and related technologies

Progressing with the development of SST networking technologies for optical and laser sensors needs the establishment of expert centres in the domain [16, 17]. Recently the first version of the expert centre technology has been deployed and tested. During period 3 the finalization of the developments and extensive test operations are under procurement. It is the objective to exploit the effective data exchange with external sensors to promote interoperability of SST systems and sensor installation. Further, the Expert Centre support for qualifying, evaluating, and calibrating sensors, and for sensor upgrades and developments, has already been demonstrated. This demonstration revealed the high potential also in supporting national activities.

European SST approaches will benefit from following a community approach for SST core software. Such an approach that defines and establishes commonly used data generation kernels and formats saves development and maintenance costs and avoids diverging service outputs. Addressing the software and not the data, the national approaches and data policies will remain fully transparent to the SST Core software, and will not be constrained. Establishing a repository for the SST core software and the related processes for the development and maintenance through a community led by ESA generates more opportunities for industry, e.g. to customise the software for national needs. Participants can decide on their contribution to the common repository from national tailoring efforts. ESA plans to initiate the community process from a consolidation of Member State requirements into a set of common requirements, and establishing the appropriate licensing scheme. This will be achieved in parallel to providing the first baseline from the integrated ESA core software. This software is currently undergoing an end-to-end functionality test and validation. The baseline software will consist of data processing, the planning and scheduling, and the application software (see Fig. 2).

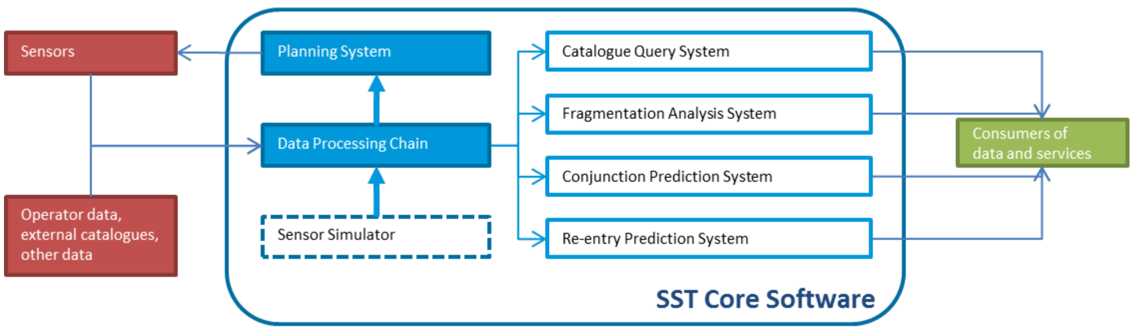

Fig. 2: SST Core Software: building blocks with simplified dataflow and boundaries.

2.3 Activities in SST Applications

SST puts the development focus on SST sensors and data processing. The already developed SST applications for collision avoidance, re-entry event prediction, fragmentation event detection and catalogue querying will be maintained and further integrated and validated using available data. The maintenance will also include the implementation of new and revised standardised message formats in support of the SST core software activities.

2.4 Collaboration aspects and standardization in SST

A new direction in the SST development in Europe came with the implementation of the EU funded Space Surveillance and Tracking Support Framework. In this complex and dynamic environment, ESA's SST work will continue supporting the development of European capabilities through research and development. These activities will be complemented by the related test and validation efforts, development of sensor technologies, data processing, and applications. Along with the development of networking technologies, a bottom-up consolidation of the evolving SST topologies in a European context can be supported using the developed tools for architecture performance analysis.

ESA will continue to support and lead activities related to SST standardisation (e.g. in the CCSDS, see as example [18]).

3. OUTLOOK

Since 2009 ESA executes an SSA programme as an optional programme of the Agency with a total financial participation of approximately 200M€ from 19 Member States. Period 3 of the programme is executed following a step-wise approach during the years 2017-2019, and continues organizing the work in 3 so-called segments: SWE, NEO, and SST. SST has received a growing support among the participating states, with 11 having declared their interest in SST for Period 3.

Research and development of SST technologies is conducted for ground-based sensor systems (radars, telescopes, and laser ranging systems), and for the development of a space-based optical component. Data processing activities will progress towards a community-based approach for the core software. New sensor developments, existing national sensors, and the integrated data processing and SST applications, are subject to pre-operational test and validation during period 3. Further developing and establishing data exchange formats in SST is very important for the progressive evolution and integration of existing assets in Europe towards an interoperable European SST system.

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. Acting as an architect of a system of systems perfectly exploits ESA's expertise. ESA has the necessary means available to assess and mature all relevant technologies in SSA for the benefit of the European citizens.

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