# DESCRIPTION OF THE ARCHITECTURE OF THE SPANISH SPACE

# SURVEILLANCE AND TRACKING SYSTEM

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## ABSTRACT

This article presents a high level description of the architecture of the Spanish Space Surveillance and Tracking (S3T) system. The system provides Space Surveillance and Tracking (SST) services with two main objectives: (a) to ensure the long-term availability of space infrastructures which are essential for the safety and security of worldwide citizens; (b) to provide the best available information to governmental and civil protection services in the event of uncontrolled re-entries of entire spacecraft or space debris thereof into the Earth's atmosphere. The SST services provided comprise (a) collision risk assessment, the generation of conjunction data messages between objects in space, (b) the detection and characterization of in-orbit fragmentations and collisions, (c) characterization and surveillance of uncontrolled re-entries of space objects into the Earth's atmosphere. In this context, the S3T system is currently contributing to the provision of these services by means of a national SST Operations Centre (S3TOC) and a set of ground-based sensors (S3TSN) which include optical surveillance and tracking telescopes and a surveillance radar. From a functional point of view, the S3TOC is composed of a data processing function, a sensor planning and tasking function and a service provision function. The data processing function is devoted to sensors' observations data processing, including correlation, orbit determination and maintenance of a catalogue of space objects observed by the S3T sensors. The sensor planning and tasking function is devoted to plan and optimise the use of the sensors' visibility slots and to command accordingly both survey and tracking sensors, based on the observation needs to maintain the catalogue and derived from the data processing and service provision functions. Moreover, the S3T catalogue is composed of object data and orbital information derived from sensor observations, external sources (e.g. JSpOC) and the ephemeris provided by satellite operators. The routine operations were initiated on the 1st of July 2016. One of the major achievements of the S3TOC to date is the creation of an autonomous catalogue based on observations from the S3T Sensor Network complemented with external data sources. For instance, this catalogue allows for the independent generation of custom Conjunction Detection Messages (CDMs) which complement the service provided by other international SST services. The processing chain requires a high level of automation and complex optimization of simultaneous processes to provide efficient and accurate products which comply with the SST user needs. The first months of operations have allowed to establish and refine operational procedures, as well as to gain experience that will be used to evolve the system in the coming years. The S3T system is a fruitful contribution to the European space surveillance and tracking framework following the European Parliament and Council decision 541/2014/EU.

Key words: Spanish Space Surveillance and Tracking, SST, Space Debris, S3T, S3TOC, S3TSN.

## 1 INTRODUCTION

The space debris population has drastically grown since the first launch of an artificial satellite in 1957 and it has become a serious threat to the security, safety and sustainability of space activities [1]. As of 1st January 2017, around 22,000 objects were tracked by the US Space Surveillance Network (SSN). Just a 4% of those objects are operational satellites while the rest are qualified as space debris [2]. In addition, the number of particles between 1 and 10 cm in size is estimated to be around 500,000 and a figure of over 100 million

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particles smaller than 1 cm has been set.

Various detrimental consequences are currently taking place due to the proliferation of space debris, such as in-orbit fragmentations, collisions or the uncontrolled re-entry of objects into the Earth's atmosphere. This has, in turn, adverse effects on the ground- and space-based infrastructures, so that it has become necessary to permanently survey and track man-made space objects to provide satellite operators with early conjunction warnings, in order to manoeuvre operational satellites and reduce the collision risk, or to provide civil protection entities with information of uncontrolled re-entries of large objects which may not disintegrate in the Earth's atmosphere.

For these reasons, in April 2014 the European Parliament and the Council of the European Union decided to establish a European Support Framework for Space Surveillance and Tracking (SST) *'to contribute to ensuring the long-term availability of the European and national space infrastructure, facilities and services which are essential for the safety and security of the economies, societies and citizens in Europe*. *The specific objectives of the SST support framework are: (a) assessing and reducing the risks to in-orbit operations of European spacecraft relating to collisions and enabling spacecraft operators to plan and carry out mitigation measures more efficiently;(b) reducing the risks relating to the launch of European spacecraft; (c) surveying uncontrolled re-entries of spacecraft or space debris into the Earth's atmosphere and providing more accurate and efficient early warnings with the aim of reducing the potential risks to the safety of Union citizens and mitigating potential damage to terrestrial infrastructure; (d) seeking to prevent the proliferation of space debris'* [3].

The SST Support Framework comprises currently five EU Member States: Spain, represented by the 'Centro para el Desarrollo Tecnológico Industrial' (CDTI); France, represented by the 'Centre National d'Études Spatiales' (CNES); Germany, represented by the 'Deutsches Zentrum für Luft- und Raumfahrt' (DLR); Italy, represented by the 'Agenzia Spaziale Italiana' (ASI); and the United Kingdom, represented by the UK Space Agency (UKSA). It is expected that this system will be fully operational in 2020, although the initial services are provided since the 1st of July 2016.

Under this context, CDTI, with funds of the Spanish Ministry of Industry and the EU, is coordinating the development and operations of the S3T system in collaboration with the Spanish Ministry of Defence, among others. In addition, the European Space Agency (ESA) is supporting CDTI in the development and procurement of the S3T System, together with a Spanish Industrial Team: INDRA Sistemas S.A., GMV Aerospace and Defence S.A.U and Deimos Space SLU.

The S3TOC operations are supported by the same Industrial Team and Hisdesat Servicios Estratégicos, S.A.

The present article focuses on the description of the architecture of the S3T system. This system is composed of the S3T Sensor Network (S3TSN) described in Section 2 and the S3T Operations Centre (S3TOC) described in Section 3. In addition, Section 4 describes the services provided by the S3T system: conjunction warning, fragmentation detection and characterization, and re-entry analysis and monitoring of uncontrolled objects. Figure 1shows a high level block diagram of the S3T system.

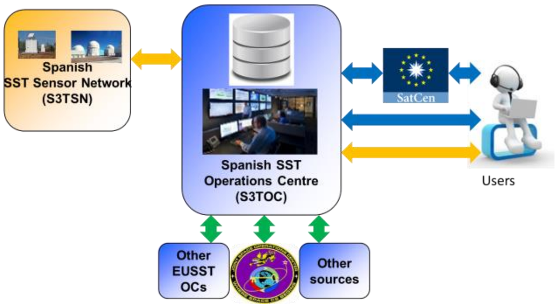


Figure 1: S3T System Block Diagram

## 2 THE S3T SENSOR NETWORK

The S3T Sensor Network is composed of optical (both passive and active) and radar sensors. The S3T sensors are tasked by the operations centre based on the catalogue and service provision needs.

Currently five optical telescopes and one radar are contributing to the network. The expansion with four additional telescopes, one laser ranging station and one more radar is on-going. Figure 2 shows some of these sensors. The list of sensors, including their survey/tracking capabilities, is described subsequently.

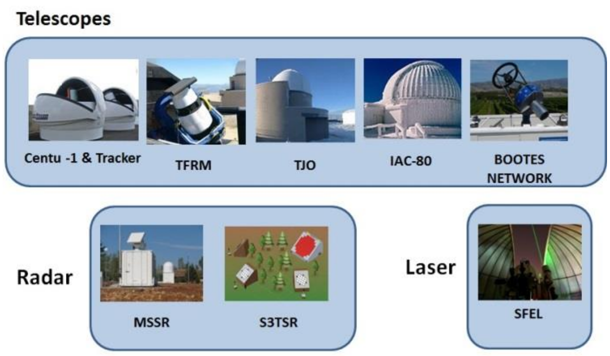


Figure 2: S3T Sensor Network

Centu-1 is a wide field of view optical telescope within the Deimos Sky Survey (DeSS) infrastructure, suitable for searching space debris on GEO and MEO regimes. It is owned by Deimos Castilla la Mancha and it has been operationally contributing to the S3T system since July 2016. It is used for surveillance, contributing to build-up and mainten the S3T catalogue [4].

TFRM is a surveillance and tracking optical telescope located in the province of Lleida (Spain). It is a joint venture between the 'Real Observatorio de la Armada' (ROA) and the 'Real Academia de Ciencias y Artes de Barcelona' (RACAB) [5]. It has been operational for S3T since July 2016 and, similarly to Centu-1, it is used for surveillance, contributing to build up and maintain the S3T catalogue.

Tracker-1 is a tracking telescope within the Deimos Sky Survey (DeSS) infrastructure, as Centu-1, and it is owned by Deimos Castilla la Mancha. It has been operational for S3T since July 2016 and is devoted to tracking objects in the MEO and GEO regimes, with the aim to improve the accuracy of the orbits in the S3T catalogue and to observe High Interest Events (HIE), as defined by the specific requirements of the users.

Telescopi Joan Oró (TJO) sensor is a 1-m class tracking telescope owned by 'Institut d'Estudis Espacials de Catalunya' (IEEC) [6]. It has been operational for the S3T since July 2016 and, similarly to Tracker-1, is mainly used for improving the accuracy of the orbits within the S3T catalogue and to observe HIE.

IAC-80: This telescope is operated on the island of Tenerife by the 'Instituto de Astrofisica de Canarias' (IAC) in the Spanish 'Observatorio del Teide'. The observatory started operations in 1964 and it is one of the world major international observatories due to its transparency and excellent astronomical sky quality. The IAC-80 telescope has been used operationally in the S3TSN since January 2017. It is used for tracking activities to improve the accuracy of the orbits within the S3T catalogue and to observe HIE.

BOOTES network: The Burst Optical Observer and Transient Exploring System (BOOTES) network [7], owned by 'Agencia Estatal Consejo Superior de Investigaciones Científicas – Instituto Astrofísica Andalucía' (CSIC-IAA), is participating in the S3TSN with one surveillance and tracking telescope (Bootes-1) and 3 tracking telescopes (Bootes 2, 3 and 5). The telescopes, located at several sites around the Earth in order to achieve global coverage of the geostationary orbit (GEO) belt, are starting gradually to contribute to the S3TSN during 2017.

Laser ROA SLR: The Laser Station of San Fernando (SFEL) is owned by 'Real Observatorio de la Armada' (ROA) and managed by the RACAB. As part of the International Laser Ranging Service (ILRS) and the Consortium of European Satellite Laser Ranging (SLR) Stations (EUROLAS) [8], it has an extensive experience in tracking satellites. It is foreseen to become operational as part of the S3TSN during the first half of 2017. This sensor is being used primarily to track cooperative objects (with retro-reflectors) in LEO.

The Monostatic Space Surveillance Radar (MSSR) is a close-monostatic L-band radar, owned by the European Space Agency (ESA). It is located in the Santorcaz military naval base, about 30 km from Madrid (Spain). Through an agreement between the Spanish Ministry of Defence and ESA, the radar has been operational within the S3TSN since the end of the year 2016. The radar is able to detect large objects from 200 to 1200 km in range and it is mainly used for re-entry campaigns.

S3T Surveillance radar (S3TSR): The new S3T Surveillance Radar (S3TSR) is presently under development. The design has been completed and it is foreseen that it will be operational and fully integrated within the S3T system by the end of 2017. The performance of the radar will be increased in the next years, taking advantage of the scalability of the proposed design.

Further information on the planning and tasking of the S3TSN may be found in Section 3.2.

## 3 THE SPANISH SST OPERATIONS CENTRE

The S3TOC is located in the Torrejón de Ardoz Military Air Base, 30 km away from Madrid (Spain). The centre is devoted to the generation of SST end-user products, for which a catalogue of objects is maintained and orbital information from SST observations obtained by the S3TSN is computed. A high level overview of the S3TOC is depicted in Figure 3.

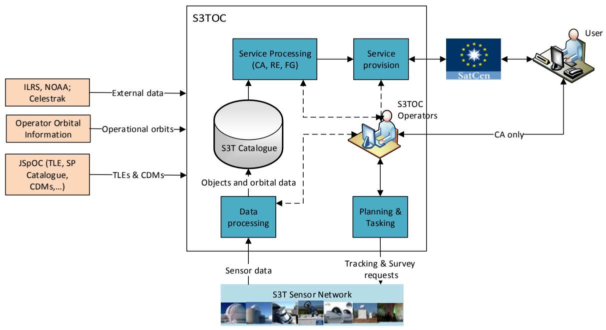


*Figure 3: S3TOC High Level Overview*

The S3TOC consists of the following elements:

The Data Processing and Cataloguing Function processes the sensor data, including correlation and orbit determination, for the generation of object data (such as object identifiers, estimated mass and area) and orbital data (position, velocity and associated covariance) to populate a catalogue of man-made space objects, called the S3T catalogue.

The Service Processing Function generates end-user SST products such as conjunctions, re-entry and fragmentations messages by carrying out collision risk, re-entry and fragmentation analyses using the S3T catalogue data and external information, such as JSpOC (e.g. TLE, CDMs) and ephemeris from satellite operators.

The Sensor Planning and Tasking Function generates tracking and survey requests for the sensors based on the observation needs derived from the Data Processing, Cataloguing and Service Processing functions.

The Service Provision Function provides SST services, including collision warning, re-entry prediction and fragmentation detection. This function considers the reception of service requests and the submission of service data as an answer to those requests.

It is worth to notice that the S3TOC software has been fully developed by Spanish industry.

### 3.1 S3TOC environments

Given the need to handle classified data, the S3TOC is currently composed of two operational environments, physically and logically separated. Additionally, an integration and reference environment is necessary for testing purposes.

OPE-unclass environment operates with unclassified information and data (e.g. from optical telescopes).

OPE-class environment is intended for operations with classified information and data (e.g. from the MSSR radar).

Pre-OPE environment: This S3TOC pre-OPE environment is intended for operators training, debugging, integration and validation activities.

### 3.2 Planning and tasking function

The tracking and survey requests to the S3TSN are generated based on the observation needs to maintain the catalogue, and to provide the services: collision prediction, fragmentation events detection and characterization and re-entry monitoring.

#### 3.2.1 Survey strategies

Each sensor follows a different survey strategy but they all pursue to survey the maximum achievable sky region, depending on the observation modes available, keeping a frequent observation profile of each object to optimise the orbital accuracy.

In the case of the telescopes, the sky region is adjusted (in declination) to follow the GEO belt, depending on the observation dates and covered longitudinal region, the declination strips shall be modified to cope with the proper right ascension-declination portion where objects within the GEO region move. The observation region is also adapted depending on the Earth shadow, Moon and Milky Way position at every particular date. The observation strategy, and thus, the observing regions are defined according to the S3TOC indications, and considering inputs from sensor operators.

According to these aspects, the longitude that can be reached by each sensor is defined and this longitude band defines the right ascension to be observed per night. Once the right ascension is defined, the declination band is selected.

#### 3.2.2 Tracking strategies

The telescopes tracking strategy employed since the starting of operations in July 2016 is described subsequently. The tracking approach is typically defined to obtain slots for each object with a duration optimised to include the tracking itself and the idle time between targets, two or three times per night. The tracking activities are requested in the basis of the following needs:

- Service needs (e.g. collision prediction, fragmentation characterisation and re-entry monitoring).
- New candidates for cataloguing filtered from the TLE JSpOC catalogue. The main idea is to increase the catalogue population based on dedicated tracking for objects that are not already catalogued by survey tasks.
- Catalogue maintenance for objects selected after the cataloguing operations. The estimated covariance is also taken into account for catalogue maintenance purposes by requesting tracking to objects with estimated covariance higher than a given threshold.

The tasking of the radar is based on re-entry prediction needs and the laser will be mainly used for tracking HIEs that involve one or more cooperative objects.

### 3.3 The S3T catalogue

The S3T catalogue is composed of an *'autonomous S3T catalogue'*, based on object and orbital information obtained from the S3T sensor data and complemented with external data sources (e.g. JSpOC) and ephemeris from the satellite owners and operators. The autonomous S3T catalogue was built from scratch, typically referred to as *'cold start'*, since $1^{st}$ July 2016. The catalogued objects are categorised based on the following naming convention:

- Active objects: objects that are considered valid and may be correlated with future observations. In order to be considered active, an object must comply with various rules based on the knowledge derived from the observation campaigns, as for example having a minimum number of tracks with a minimum duration and a maximum latency between the tracks. These conditions are tailored depending on the orbital regime of the object.

- Confirmed objects: objects that have been observed along a long interval of time, so it can be confirmed that the object is real and can be properly maintained. In order for an object to be confirmed, it must be observed for a span covering at least three days.
- Objects correlated to TLE: Objects that can be correlated to an object in the public two-line element (TLE) catalogue in space-track.org [9].

As of 26th January 2017, the autonomous S3T catalogue contains 866 active objects, 757 confirmed objects and 608 objects correlated to TLEs.

Figure 4 illustrates the evolution of the confirmed and correlated to TLE objects since the beginning of operations.

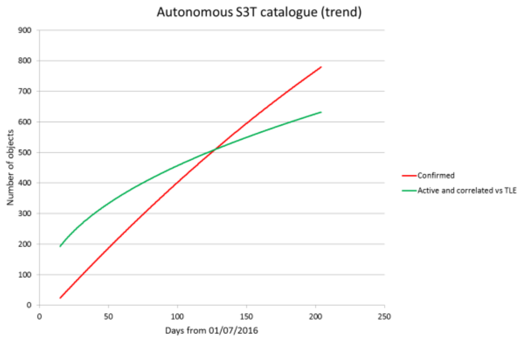


*Figure 4: S3T Autonomous Catalogue*

The whole cataloguing chain is automated. However, the maintenance of some particularly complex objects in the S3T catalogue requires the involvement of the S3TOC operators. These objects are described subsequently.

- Maintenance of manoeuvrable objects: These objects are particularly difficult to keep in the catalogue when the manoeuvre plan of the satellite is not available. When a satellite manoeuvres, the orbit needs to be re-initialised.
- Maintenance of clustered satellites: Objects flying in close formation are particularly challenging to maintain. They perform frequent manoeuvres and they lead to frequent miscorrelations due to their apparent positions shift.
- Maintenance of operational unidentified flying objects (UFOs): The maintenance of operational objects which are not present in any public external catalogue (e.g. JSpOC) is a demanding task. Non-manoeuvrable UFOs can be maintained for extremely long times. However, operational UFOs are extremely hard to maintain.
- Maintenance of highly eccentric objects: These objects are observed sparsely which makes their maintenance in the catalogue more arduous. Moreover, GTO objects with low perigee are more complex to model due to the uncertainties of the atmospheric drag.

## 4 SST SERVICES

The S3T system provides the three services described in Sections 4.1, 4.2 and 4.3.

These services are currently provided through the EU SST Service Provision Portal [10]. EU SST users include the European Commission, the Council, EU Member States, the European External Action Service (EEAS), public and private spacecraft owner and operators and public authorities concerned with civil protection.

### 4.1 Conjunction warning

The S3T system analyses the risk of conjunctions between man-made objects in-orbit in order to produce collision avoidance alerts for the satellite operators when necessary.

If a High Interest Event (HIE) is predicted, a dedicated follow-up of the primary and secondary objects is carried out with the S3TSN in order to better characterize the event. Typically, the conjunction assessment is carried out once per day unless a higher periodicity is required due to a warning event.

Customised Conjunction Data Messages (CDMs) are produced based on the S3T Catalogue using the data delivered by the S3TSN and/or the post-processing of external data from other sources (e.g. JSpOC CDMs).

Figure 5 shows HIEs of some GEO satellites computed by the S3TOC based on the S3T Catalogue and the observations within the accessible sky region of the S3TSN.

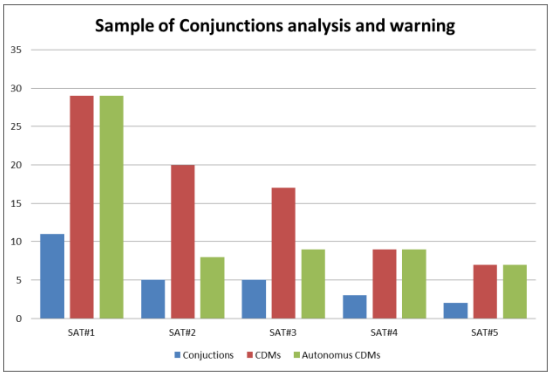


*Figure 5: Sample of Detected conjunctions and CDMs of 5 GEO satellites in 1Q2017*

One of the major achievements of the S3T system to date is the generation of autonomous and customised alerts not dependent on external sources (e.g. JSpOC data). Moreover, the S3T is able to adapt to the satellite operator needs and provide a customised added value to the service including:

- External CDM analysis with improved orbital information.
    - Owner/Operator (O/O) ephemerides (primary) containing the foreseen manoeuvres.
    - Satellite or space debris data obtained with survey and tracking sensors of the S3T network and other sources.

- O/O ephemerides calibration based on an independent orbit determination using S3T sensors.

- Conjunction geometry analysis. B-Plane plots and time evolution plots.

- Mitigation check. When Operators compute their own manoeuvres based on their own station-keeping strategies, the S3TOC offers support to check the operational orbit taking into account the risk mitigation manoeuvre.

- Manoeuvre support: the Operators iterate with the user the potential variation of the collision risk in a HIE caused by a manoeuvre planned by the spacecraft O/O. This analysis takes into account the O/O manoeuvre strategies and current constraints, and involves close cooperation between the S3TOC and the user. The results of these analyses are the recommendations in terms of mitigation possibilities.

Furthermore, it is envisaged, as evolution of the collision avoidance service, the generation of alerts during the launch, early orbit and disposal phases, which are already being successfully pre-operationally tested.

As an example of the follow-up of launch and early operations phases (LEOP), the S3TSN monitored the first telecommunications satellite to use the SmallGEO platform, Hispasat 36W-1, launched from Kourou on the 27$^{th}$ January 2017. Figure 6 was obtained by the TFRM, working in tracking mode for this particular case, on the 29$^{th}$ January 2017 and shows the satellite Hispasat 36W-1 together with the last stage of Soyuz launcher.

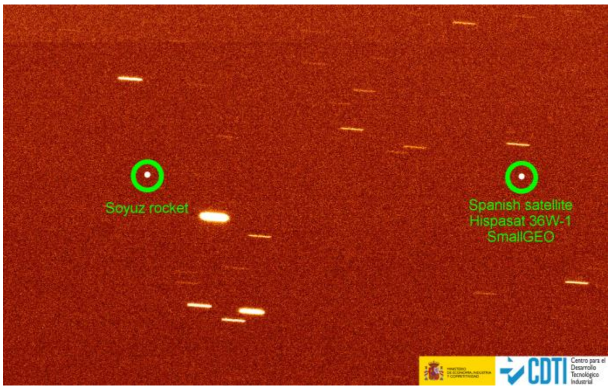


*Figure 6: Image obtained by TFRM telescope on the 29$^{th}$ January 2017 of the satellite Hispasat 36W-1 and the last stage of Soyuz launcher*

### 4.2 Fragmentation detection and characterization

The S3T system is prepared to detect and characterise in-orbit fragmentations, break-ups or collisions.

If a fragmentation takes place within the accessible region of the sensors contributing to the S3T system, the S3TOC will command dedicated follow-up of the fragments or survey of the fragmentation region in order to detect, characterise and store them in the S3T catalogue. If a fragmentation occurs outside the accessible region of the S3TSN, external data sources are used in combination with the S3T software tools to analyse the event and update the S3T catalogue.

### 4.3 Monitoring of uncontrolled re-entries

The S3T system is also prepared to assess uncontrolled re-entries into the Earth's atmosphere in order to estimate the time frame and likely location of possible impact. The following analyses can be carried out:

- Re-entry analysis based on JSpOC post-processed information: Post processing of Trajectory Impact Prediction (TIPs) and TLEs.
- Re-entry analysis with improved orbit accuracy using the MSSR radar at Santorcaz: The S3TOC can provide support during the re-entry of a space object by tracking campaigns and analysis.
- Re-entry forecast up to 60 days.

## 5 CONCLUSIONS

The S3T System has been successfully operational for eight months. One of the major achievements to date is the creation of an autonomous catalogue from a cold start, based on the data obtained from the S3T Sensor Network (S3TSN). The catalogue is growing steadily and it provides autonomy to the system. As of 26$^{th}$ of January 2017, the autonomous S3T catalogue contains more than 700 confirmed objects, including several

UFOs.

Currently five optical telescopes and one radar are contributing to the S3TSN, which is being complemented in 2017 by additional telescopes, a laser ranging station and one scalable survey radar system. The new S3T surveillance radar will be fully integrated in the S3T system by the end of 2017 and it will enhance the S3T service capabilities in LEO. It is foreseen to evolve the capabilities of the S3TOC in parallel to the increase of the sensors contributing to the S3TSN.

The sensor data is automatically ingested and processed by the S3T cataloguing system, followed, in specific cases, by manual procedures performed by the S3TOC operators for the maintenance of particularly complex objects, like clusters, operational UFOs or highly eccentric objects. The three services currently provided by the S3T system comprise: (a) the risk assessment of in-orbit collisions and generation of collision avoidance alerts, (b) the detection and characterization of in-orbit fragmentations and (c) the risk assessment of uncontrolled re-entries into the Earth's atmosphere. The autonomous S3T catalogue allows for the computation of conjunctions data messages (CDMs) based on S3T sensor data customised to the needs of each satellite operator.

The S3T system has proven to be a successful SST system that helps to ensure the long-term availability of space infrastructures and to reduce the risk on-ground. Its establishment and on-going growth has become a reality thanks to the cooperation of numerous Spanish entities as well as the Spanish participation in EU-SST framework activities.

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Support received by the Spanish Administration deserves special mention, in particular for Industry, Defence, Presidency and Home Affairs Ministries.

Last, but not least, the users, whose feedback is a key aspect for the system operations and development.

## REFERENCES

1. Inter-Agency Space Debris Coordination Committee, *Space Debris. IADC Assessment Report for 2011*, IADC-12-06, April 2013.
2. Biesbroek, R., *Active Debris Removal in Space: How to Clean the Earth's Environment from Space Debris*, CreateSpace Independent Publishing Platform, 2015.
3. European Parliament and the Council of the EU, *Decision No 541/2014/EU of the European Parliament and the Council of the European Union of 16 April 2014 establishing a Framework for Space Surveillance and Tracking Support*, Official Journal of the European Union, Strasbourg, 16 April 2014.
4. Jaime Nomen Torres, Noelia Sánchez-Ortiz, Raúl Domínguez-González, Nuria Guijarro López, Pablo A. Quiles Ibernón *Accurate Optical Observations of Space Objects in GEO and applicability to closer LEO regimes*, Space Debris Conference, Darmstadt, 2017.
5. Fors O., Montojo F.J., Núñez J., Muios J.L., Boloix, J., Baena R., Morcillo R., Merino M., *Status of Telescope Fabra ROA at Montsec: Optical Observations for Space Surveillance & Tracking*, AMOS conference, Maui, Hawaii, USA, 2011.
6. Vilardell, F., Colomé, J., Sanz, J., Gil, P., Ribas, I., *Observing with the Telescopi Joan Oró*, Highlights of Spanish Astrophysics VII, Proceedings of the X Scientific Meeting of the Spanish Astronomical Society (SEA), 958-958, 2013.
7. Castro-Tirado, A. J., Jelínek, M., Gorosabel, J., Kubánek, P., Cunniffe, R., Guziy, S., et al. *Building the BOOTES world-wide Network of Robotic telescopes*, Astronomical Society of India Conference Series, vol. 7, 2012, pp. 313-320.
8. Catalán, M., Quijano, M., Pazos, A., Martín Dávila, J., Cortina, L. M., *Space Debris Tracking at San Fernando Laser Station*, Revista Mexicana de Astronomía y Astrofísica Conference Series 48, 103-106, 2016.
9. Space Track team. URL: http://www.space-track.org/.
10. European SST Service Provision Portal, URL: https://sst.satcen.europa.eu.