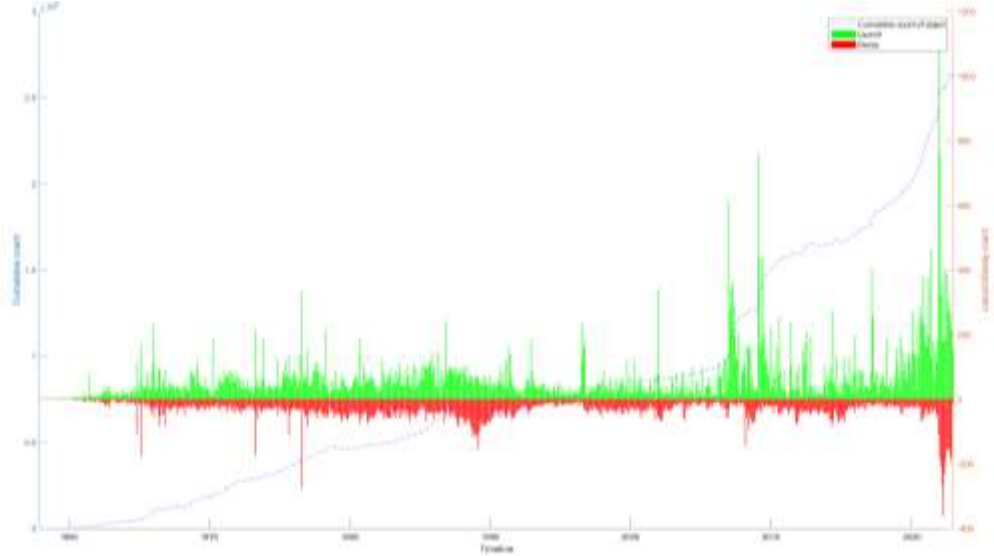
European Space surveillance and tracking 2023 – 2026 R&D activities

EU SST
Space Surveillance and Tracking

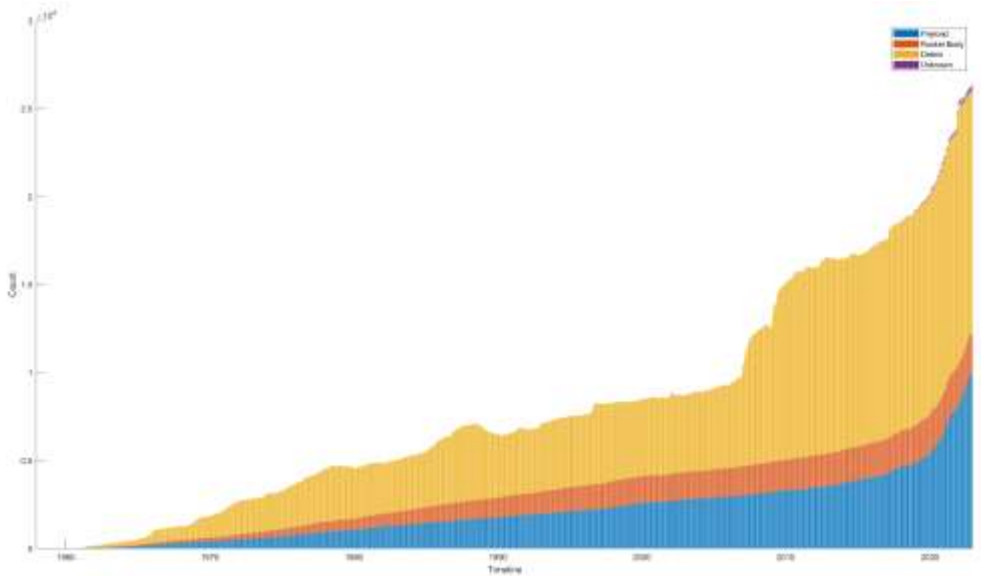
Cassien Jobic (CNES)*, E. Delande, C. Perez, A. Di cecco, C. Vogt, D. Stelmecke, J. Gelhaus

Head of the Expert Team System Evolution

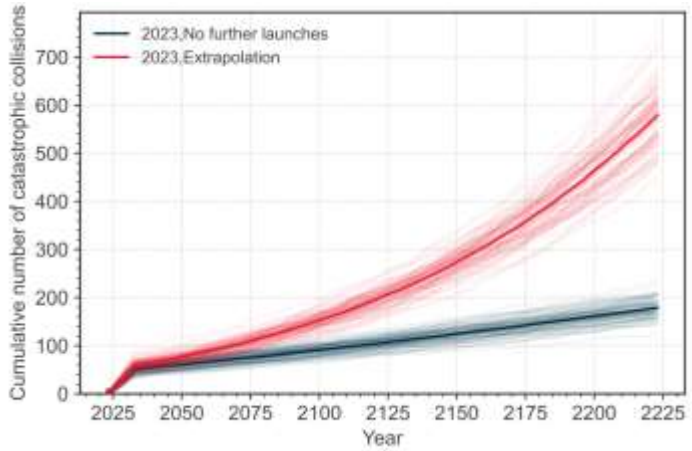
Space Situational Awareness – Status report and previsions



Number of Launch and Decay per month and the cumulative count of object remained in orbit as function of Time (Source : Spacetrack)



Number of object orbiting around Earth per type: Payload, Rocket Body, Debris and unknown object (Source : Spacetrack)



Number of cumulative collisions in LEO in the simulated scenarios of long-term evolution of the environment (Source : Esa's annual space environment report)

→ A Scalable and efficient SST environment is required

Service provision ▪ 3 Operational & Added Value Services

Collision Avoidance (CA)

Risk assessment of collision and generation of collision avoidance alerts

Fragmentation Analysis (FG)

Detection and characterisation of in-orbit fragmentations

Re-entry Analysis (RE)

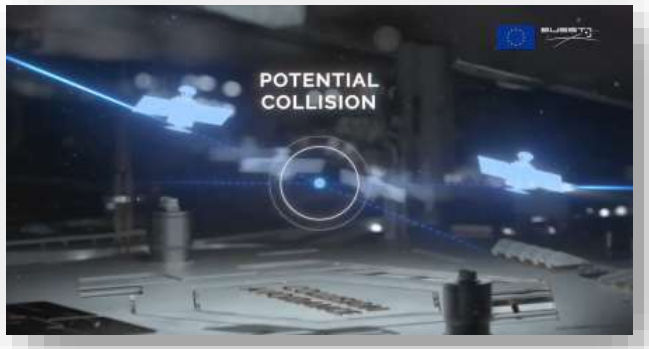
Risk assessment of space objects re-entry into the Earth's atmosphere

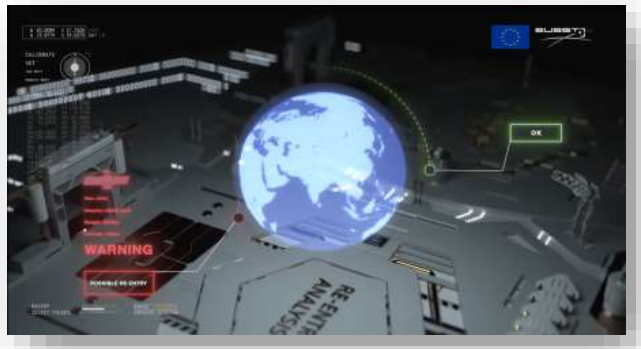
Key features

- **User-tailored** service (SCD)
- Hot redundancy scheme involving ES (S3TOC) and FR (FR-SSA) with harmonised service level and single service provider per registered user
- Enhanced **Analysis & Risk Mitigation** support (e.g. covariance estimations, HBR estimations, PoC sensitivity analysis, CAM support)

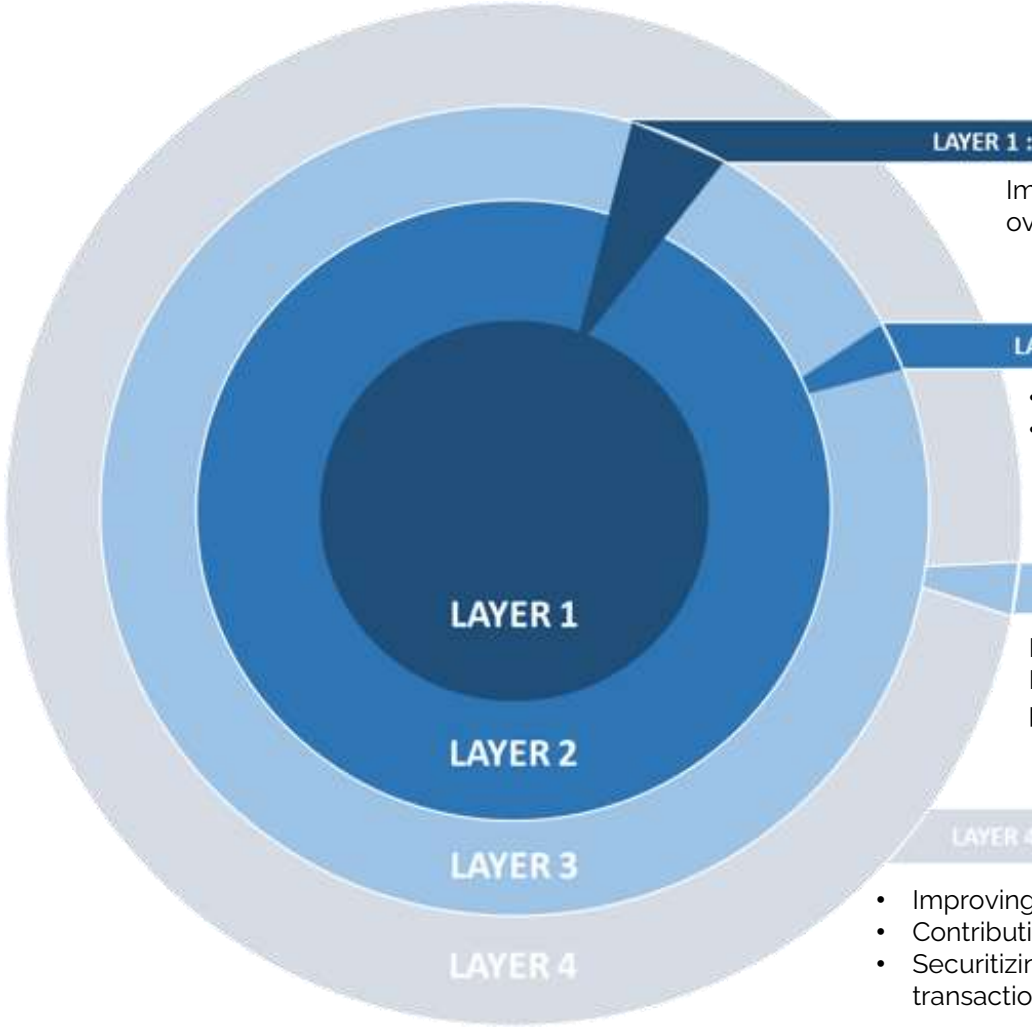
- Provided by IT (C-SSA)
- Short-term notification to **confirm quickly an FG event**
- Medium-term FG analysis based on the orbital parameters of the **catalogued fragments** e.g. Gabbard Diagram
- Long-term FG analysis (**with simulations with breakup model**)

- Provided by IT (C-SSA)
- Long-term (within 30 days) **re-entry predictions**
- Short-term (a few days) overflight predictions with **ground tracks over customisable areas of interest**





EU SST – Development strategy



LAYER 1 : DATA ACQUISITION

Improving the detectability and observability of overall objects orbiting the Earth

LAYER 2 : CATALOGUING

- Improving the number of objects identified
- Improving the quality of orbits in the catalogue

LAYER 3 : SERVICE PROVISION

Improving process and scalability of the CA, RE and FG service regarding the future space population

LAYER 4 : ECOSYSTEM AND KNOWLEDGE IMPROVEMENT

- Improving space situational awareness
- Contributing to new services (ADR, EOL, OOS)
- Securitizing and monitoring flux and data transactions

Layer 1 – Data Acquisition

LAYER 1

LAYER 2

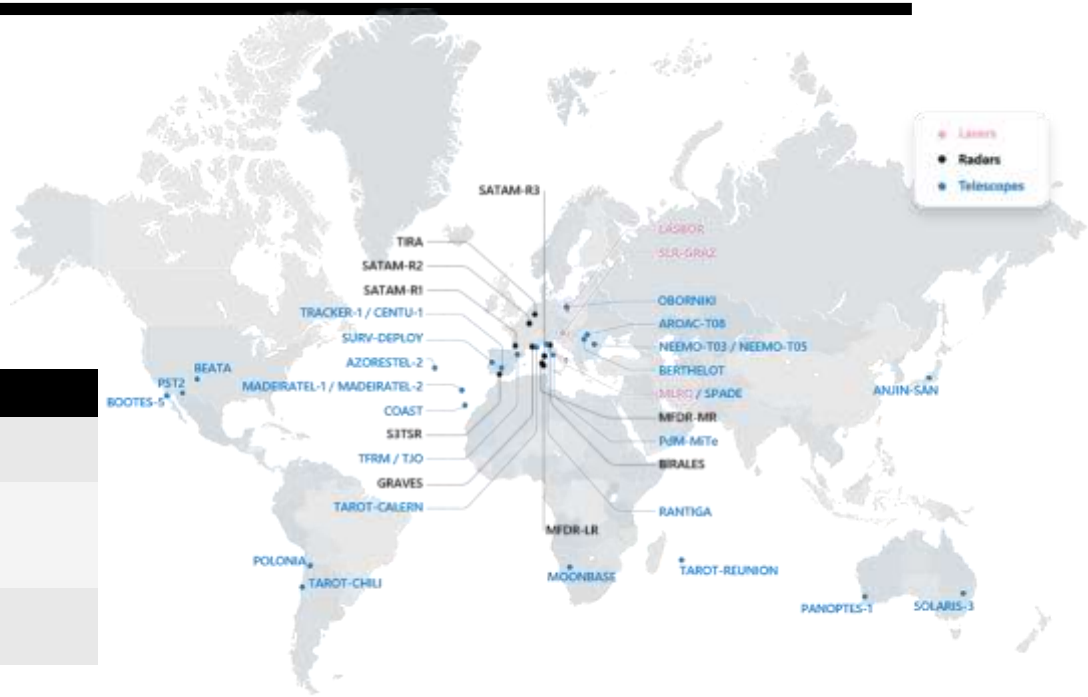
LAYER 3

LAYER 4

Patrimonial sensors improvement

Innovative commercial sensors

Space-Based Surveillance System



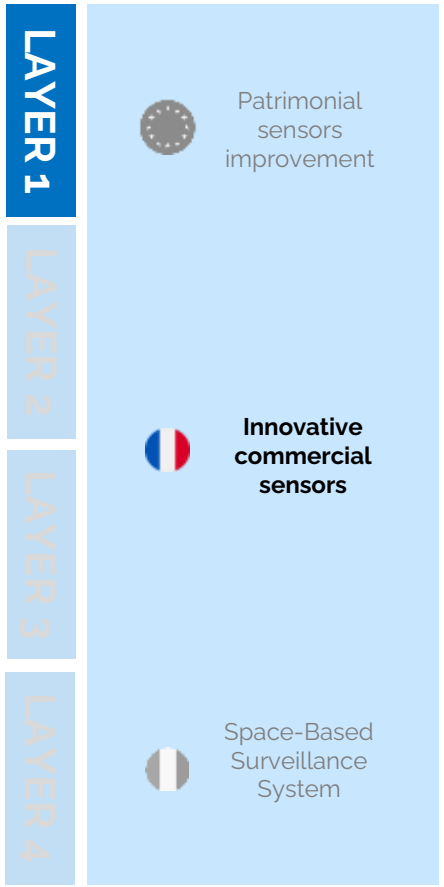
RADARS

	Upgrade
ES-S3TSR	Almost all objects bigger than 12cm
FR-GRAVES	• Almost all object bigger than 1m • 85% objects bigger than 50cm • 25% objects bigger than 25cm
FR-GRAVES-NG	• Almost all object bigger than 50cm • 70% objects bigger than 10cm

OPTICAL

	Upgrade
CZ SHOT	New CMOS camera to observe LEO, MEO and GEO
FR-TAROT*	Real-time observation scheduling optimizations
GR-KRYONERI	Increasing quality of LEO, MEO and GEO data and reactivity of the system
GR-BAKER-NUNN	• 30% objects bigger than 35cm in GEO • 77% objects bigger than 35cm in MEO
PT-SURV-DEPLOY	Reallocated to Oceania

Layer 1 – Data Acquisition



- **Sharing the burden related to the development of innovative solutions**
- **Promoting the European Industry**
- **Contributing to improving cataloguing capabilities (by 2026):**
  - **LEO :**
    - **50% of the objects above 7cm**
    - **70% above 10cm**
  - **MEO/GEO:**
    - **All objects above 35cm**
- **Being able to characterize objects orbiting the Earth**

Layer 1 – Data Acquisition

LAYER 1

LAYER 2

LAYER 3

LAYER 4

Patrimonial sensors improvement

Innovative commercial sensors

Space-Based Surveillance System

Task 1: Benchmark and test

- **Benchmarking technology capabilities and performances for SBSS applications**
- **Building-up a breadboard to test the system in near real conditions**
- **Lossless algorithm design and implementation**
- **On-board / On-ground optimal task delegation**

Task 2: Optical capabilities

- **Designing the optimal optical observation strategy contributing to SST**
- **Identifying the best observation / observed objects configuration as function of (non-exhaustive list) :**
  - **Sub GEO -> GEO**
  - **GEO -> MEO**

Task 3: Future missions

- **Simulating complete SBSS mission (satellite + ground segment) to face the different constraints**
- **Assessing on-board cross technology based solutions (non exhaustive list):**
  - **Optical + Passive RF**
  - **Optical + Laser**

Layer 2 – Cataloguing

LAYER 1
LAYER 2
LAYER 3
LAYER 4

Lasers contribution

Cataloguing algorithms

Long-term processing

LASERS

	Current Situation
Quality	$RMS \leq 20m$ on cooperative objects
Object limitations	Not accurate enough on uncooperative objects (98,8% of objects orbiting the Earth)
Observation limitations	Useable in Full night

Objectives

- **Improving catalogue methods to include lasers data related to uncooperative objects**
- **Assessing daylight tracking feasibility**
- **Assessing transversal improvement feasibility thanks to lasers data**

Layer 2 – Cataloguing

LAYER 1
LAYER 2
LAYER 3
LAYER 4

Lasers contribution

Cataloguing algorithms

Long-term processing

Task 1: Model and set of parameters

- Assessing consequences of propagations and models on catalogue accuracy
- Identifying optimal configuration per orbital regime considering:
  - Accuracy
  - Computational runtime

Task 2: Space Weather

- Assessing consequences of the error of space weather model in propagated orbits
- Enhancing realism by modeling the error (e.g. solar activity, atmospheric model)

Task 3: New methods or technics

- Assessing the feasibility to use dual-frequency tracking radars for cataloguing

Layer 2 – Cataloguing

LAYER 1
LAYER 2
LAYER 3
LAYER 4

Lasers contribution

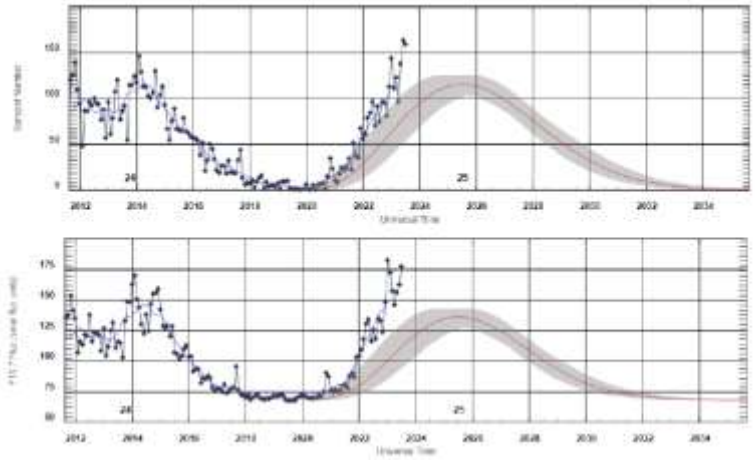
Cataloguing algorithms

Long-term processing

Propagation method:

- **Numerical (Runge-Kutta, Dormand-Prince, …) → Relatively accurate (in short time) but time consumer**
- **Analytical (SGP4) → Efficient but accuracy is limited**
- **Many uncertainties origin (such as geometry, attitude, dissipative force model)**

→ Need a compromise between uncertainties and computation time



Sunspot (on top) and 10,7cm predicted flux (on the bottom) with projection (red) and uncertainties (grey)
(Source : Space Weather Prediction Center)

Objectives

- **Modeling uncertainties in analytical propagation**
- **Modeling error model (such as thermosphere densities)**

Layer 3 – Service Provision

LAYER 1
LAYER 2
LAYER 3
LAYER 4

Collision Avoidance Service Improvement

R&D on RE

R&D on Fragmentation

Task 1: Exhaustivity

- Developing All vs All optimized screening environment
- Developing uncertainties characterization method and algorithms
- Improving risk estimations methods thanks to alternative methods (e.g Hall, LAAS)

Task 2: Maneuver computation

- Performing Maneuver Computation to provide operative recommendations

Task 3: Risks at launch

- Implementing risk assessment at launch methods (CNES method inheritance) to provide operative recommendations

Layer 3 – Service Provision

LAYER 1
LAYER 2
LAYER 3
LAYER 4

Collision Avoidance Service Improvement

R&D on RE

R&D on Fragmentation

Task 1: Realism improvement

- **Uncertainties characterization reworks based on Scaled Ballistic Coefficient, taking into account Orbital covariance**
- **Propagation methods improvement in low altitude phase**

Task 2: Break-up model improvement

- **Implementing MonteCarlo breakup simulation to evaluate fragments spread**

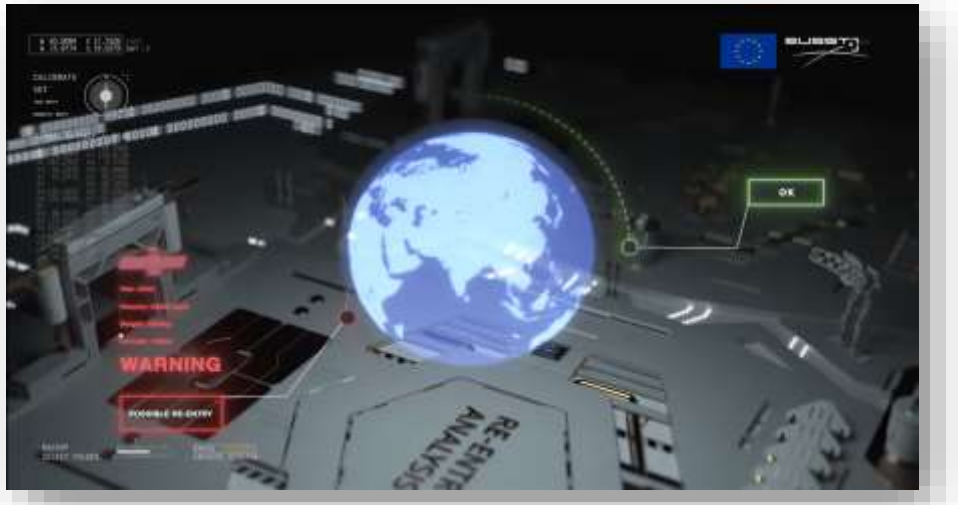
Layer 3 – Service Provision

LAYER 1
LAYER 2
LAYER 3
LAYER 4

Collision Avoidance Service Improvement

R&D on RE

R&D on Fragmentation



Task 1: Realism improvement

- Implementing Large vs Large concept for chain reactions assessment
- Increasing cooperation with CA service

Task 2: Break-up model improvement

- Implementing MonteCarlo breakup simulation to evaluate fragments spread
- Enhancing the model thanks to real fragments orbital information

Layer 4 - Ecosystem and knowledge improvement

LAYER 1
LAYER 2
LAYER 3
LAYER 4

- **Space population evolution and potential hazardous objects**
- Environmental Index
- Manœuvre detection from data fusion
- Attitude mode detection from data fusion
- Interference prediction
- Simulation bench and twin concept
- Data Governance system

- **Building EU SST space population model based on pragmatic scenarios**
- **Defining long-term scenarios taking into account :**
  - **Effect of incremental number of object increasing**
  - **Effect of satellites spiraling-up / down**
  - **Effect of satellite defects**
  - **Effect of fragmentations**
- **Quantifying the potential of any mission to degrade the orbital environment**
- **Implementing Long-term statistical / stochastic propagation**
- **Assessing the accumulated risk for a satellite (or constellation) overall the duration of the mission**
- **Analyzing space capacity and consequences of future mission**

Layer 4 - Ecosystem and knowledge improvement

LAYER 1

LAYER 2

LAYER 3

LAYER 4

- Space population evolution and potential hazardous objects
- **Environmental Index**
- Manœuvre detection from data fusion
- Attitude mode detection from data fusion
- Interference prediction
- Simulation bench and twin concept
- Data Governance system

Preparing potential future EU SST service : Compliancy reporting with Space Debris Mitigation Standards

Increasing EU SST autonomy regarding this highly strategic topic

Acting as major stakeholder in STM regulation works

Defining useful set of indicators for assessing compliancy

Defining sources and data fusion process to collect data of interest for assessing compliancy

Designing Compliancy Monitoring Software

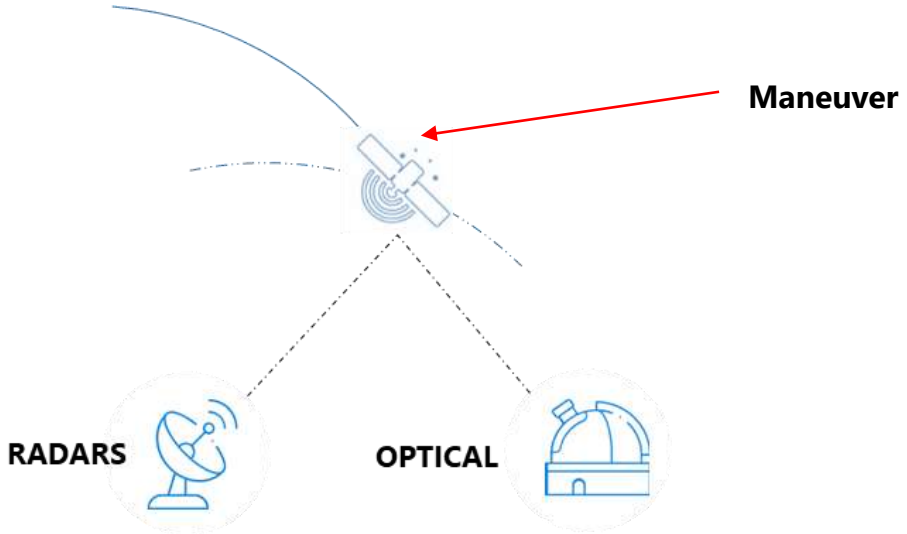
KPIs list and recommendations to assess compliancy

System requirements to implement in the future the Compliancy Monitoring Software

Layer 4 - Ecosystem and knowledge improvement

LAYER 1
LAYER 2
LAYER 3
LAYER 4

- Space population evolution and potential hazardous objects
- Environmental Index
- **Manœuvre detection from data fusion**
- Attitude mode detection from data fusion
- Interference prediction
- Simulation bench and twin concept
- Data Governance system



Task 1: Method improvement

- **Developing and implementing filtering methods helping for maneuver detection**
- **Implementing new propulsion model (such as low-thrust model) and strategies (such as station-keeping) for detecting maneuvers**

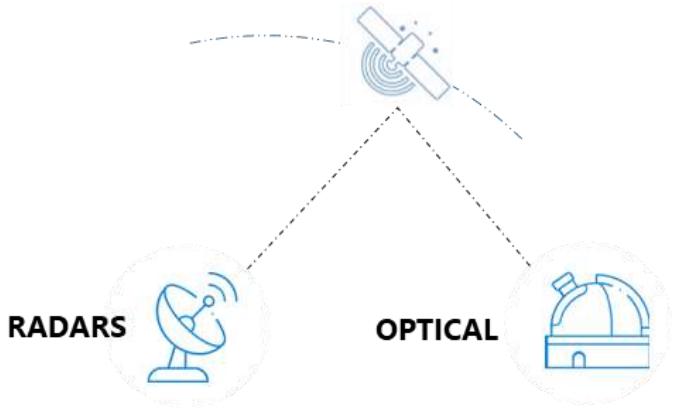
Task 2: Detection methods

- **Assessing different methods feasibility and performances for maneuver detection:**
  - **Stochastic methods**
  - **Artificial methods**
  - **Statistical methods**
  - **Data fusion based correlation (radar + optical)**
- **Assessing data fusion influence on maneuver detection feasibility**

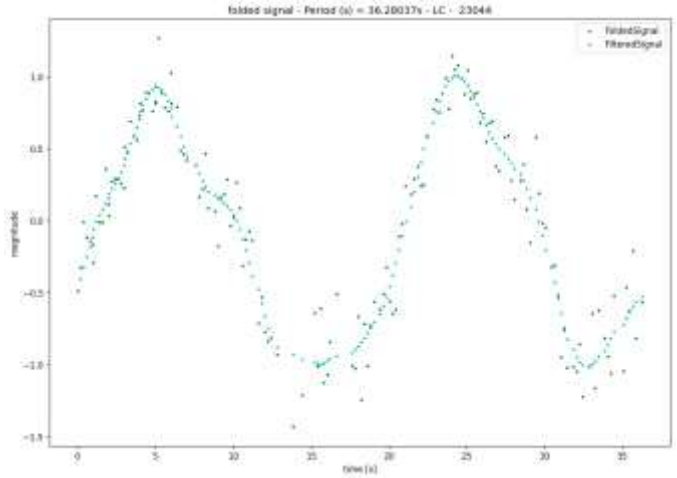
Layer 4 - Ecosystem and knowledge improvement

LAYER 1
LAYER 2
LAYER 3
LAYER 4

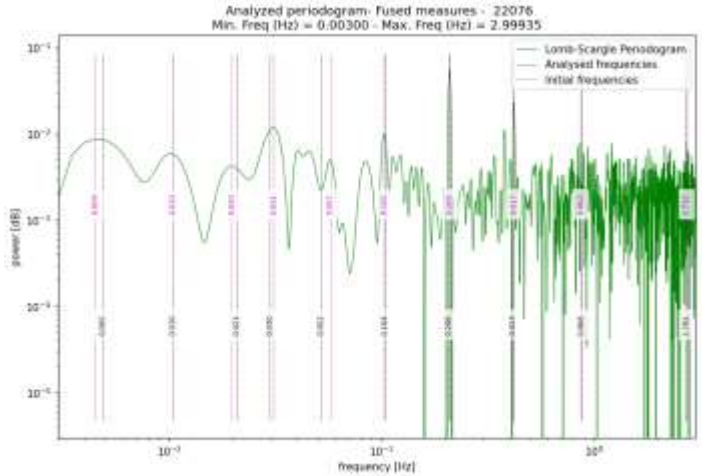
- Space population evolution and potential hazardous objects
- Environmental Index
- Manœuvre detection from data fusion
- **Attitude mode detection from data fusion**
- Interference prediction
- Simulation bench and twin concept
- Data Governance system



- **Implementing data fusion environment to collect and process cross-technologies data (optical, radars)**
- **Assessing AI-based attitude estimation feasibility (CNES previous studies inheritance)**
- **Assessing adaptive optics based attitude estimation feasibility**
- **Implementing analysis environment :**
  - **Providing attitude regime analysis to support ADR operators**
  - **Providing long-term analysis for End Of Life activities, especially assessing compliancy with EoL requirements**



Detrended light curve of COSMOS 2277 satellite in tumbling at 36.28s and epoch folding showing mean folded data obtained
(Source : EU SST Studies)

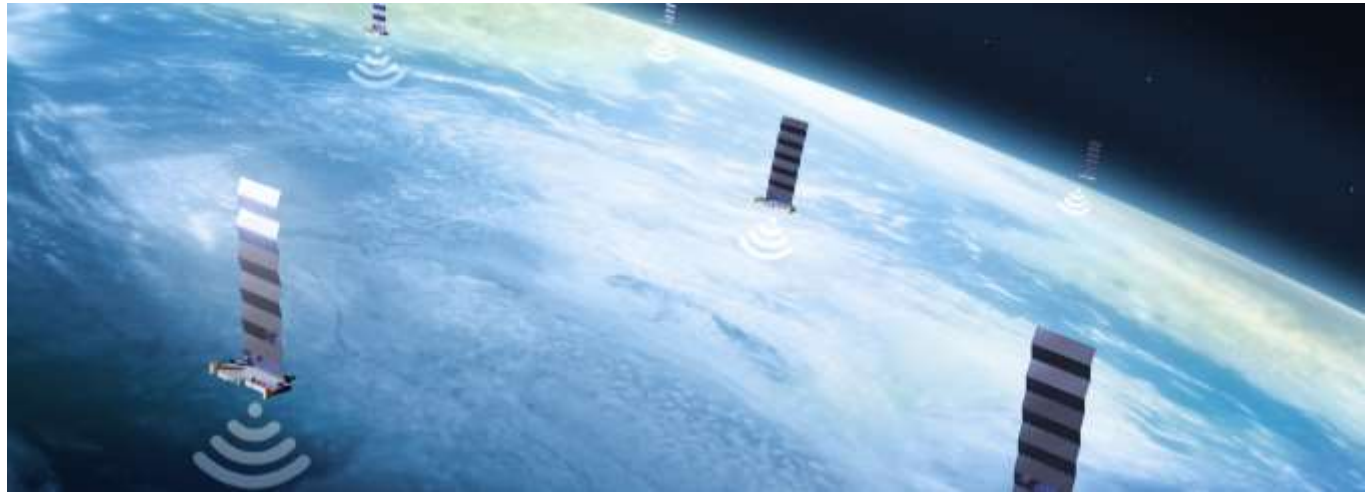


Example of selected candidates (initial frequencies in plot) and optimized candidates (analyzed frequencies in plot)
(Source : EU SST Studies)

Layer 4 - Ecosystem and knowledge improvement

LAYER 1
LAYER 2
LAYER 3
LAYER 4

- Space population evolution and potential hazardous objects
- Environmental Index
- Manœuvre detection from data fusion
- Attitude mode detection from data fusion
- **Interference prediction**
- Simulation bench and twin concept
- Data Governance system



Task 1: Knowledge improvement

- **Implementing algorithm dedicated to extract third party emissions from ground station antenna logs**
- **Developing the database hosting observations and object frequency analysis**

Task 2: Simulation environment

- **Developing emission predictions environment**
- **Developing automated RFI detection**

Layer 4 - Ecosystem and knowledge improvement

LAYER 1
LAYER 2
LAYER 3
LAYER 4

- Space population evolution and potential hazardous objects
- Environmental Index
- Manœuvre detection from data fusion
- Attitude mode detection from data fusion
- Interference prediction
- **Simulation bench and twin concept**
- Data Governance process

Objectives

- **Improving realism of the Architecture design environment**
- **Assessing long-term scalability of EU SST**

Technical content

- **Implementing twin concept in current architecture software**
- **Implementing synthetic population replicating the real current population observable**
- **Modeling Network Coordinated Scheduler (COPLA) within both FR / ES simulation chains**
- **Implementing CA / RE / FG simulation modules based on EU SST long-term population file**

Outputs

- **Highest realistic simulation short and long-term simulation environment**
- **Improved bank of simulation for assessing EU SST scalability and development plan**
- **Improved development decision making process**

Layer 4 - Ecosystem and knowledge improvement

LAYER 1
LAYER 2
LAYER 3
LAYER 4

- Space population evolution and potential hazardous objects
- Environmental Index
- Manœuvre detection from data fusion
- Attitude mode detection from data fusion
- Interference prediction
- Simulation bench and twin concept
- **Data Governance System**

Objectives

- **Assessing the feasibility to use DLT to contribute to secure data and transactions**
- **Implementing an operative Proof of Concept**

Technical content

- **Assessing the best technology to protect transactions (such as DLT)**
- **Implementing a bank test to manage measurements (data volume extracted from last year)**
- **Implementing a bank test to manage catalogue (data volume extracted from last year)**
- **Simulating use as operational environment to provide services**

Outputs

- **Recommendations on feasibility to use DLT (and which one) to manage EU SST data**
- **Proof of Concept to manage multi-layer system of data based on DLT**

Thank you

User Registration
https://sst.satcen.europa.eu

General Information
www.eusst.eu

EU SST
Space Surveillance and Tracking