# System Approach to Analyse the Performance of the current and future EU SST system at Service provision level

Igone Urdampilleta

The EU SST activities have received funding from the European Union programmes, notably from the Horizon 2020 research and innovation programme under grant agreements No 760459, No 952852, No 785257, No 713630 and No 713762, and the Copernicus and Galileo programme under grant agreements No 299/G/GRO/COPE/19/11109, No 237/G/GRO/COPE/16/8935 and No 203/G/GRO/COPE/15/7987. The content of this presentation reflects only the view of the SST Cooperation. The European Commission and the European Health and Digital Executive Agency are not responsible for any use that may be made of the information it contains.

# Introduction

- Description of the system engineering tool evolution used to evaluate the performance of EU SST system at **service provision** level:
  - Collision Avoidance (CA)
  - Atmospheric Re-entry analysis (RE)
  - Fragmentation analysis (FG)

- Description of methodology, simulation techniques and hypotheses adopted.

- Executed by two different engineering teams with independent tools:
  - AS4/*Ssasim*
  - BAS3E

- **Overall objective**: provide decision makers with quantitative analyses, towards a "best value for money" architecture design for the EU SST sensor network.

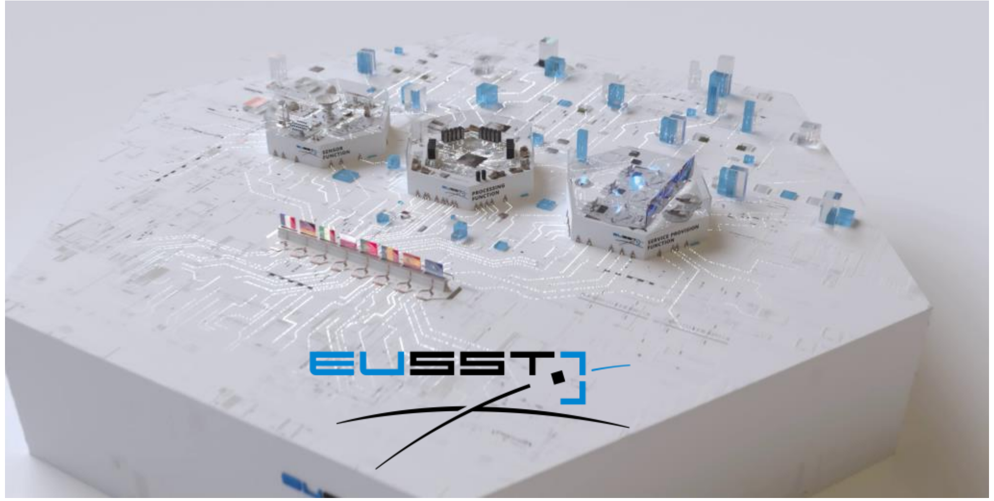
# EU SST in a nutshell

## EU SST Consortium:

7 EU Member States

- France, Germany, Italy, Spain, Poland, Portugal, Romania

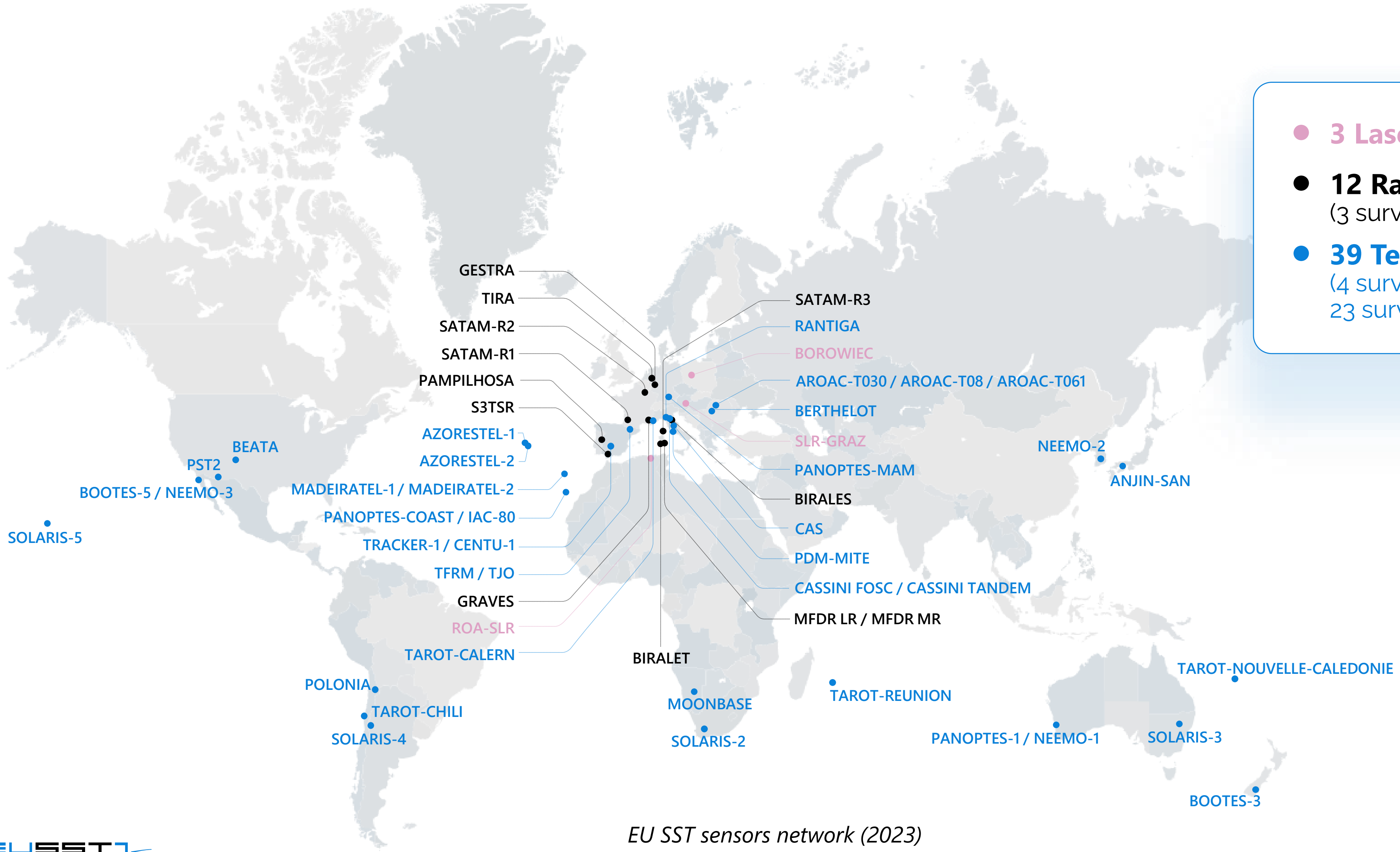
POLSKA AGENCJA KOSMICZNA



Cooperation with
**EU SatCen** as Front Desk

Overseen by
**European Commission**

# EU SST sensors network

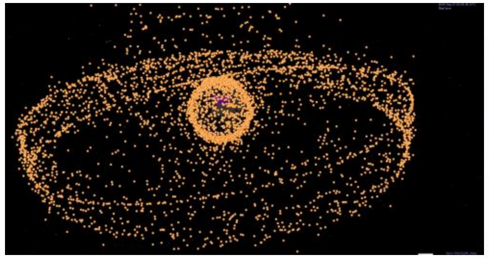



- **3 Lasers**
- **12 Radars**
  (3 surveillance, 9 tracking)
- **39 Telescopes**
  (4 surveillance, 12 tracking, 23 surveillance & tracking)

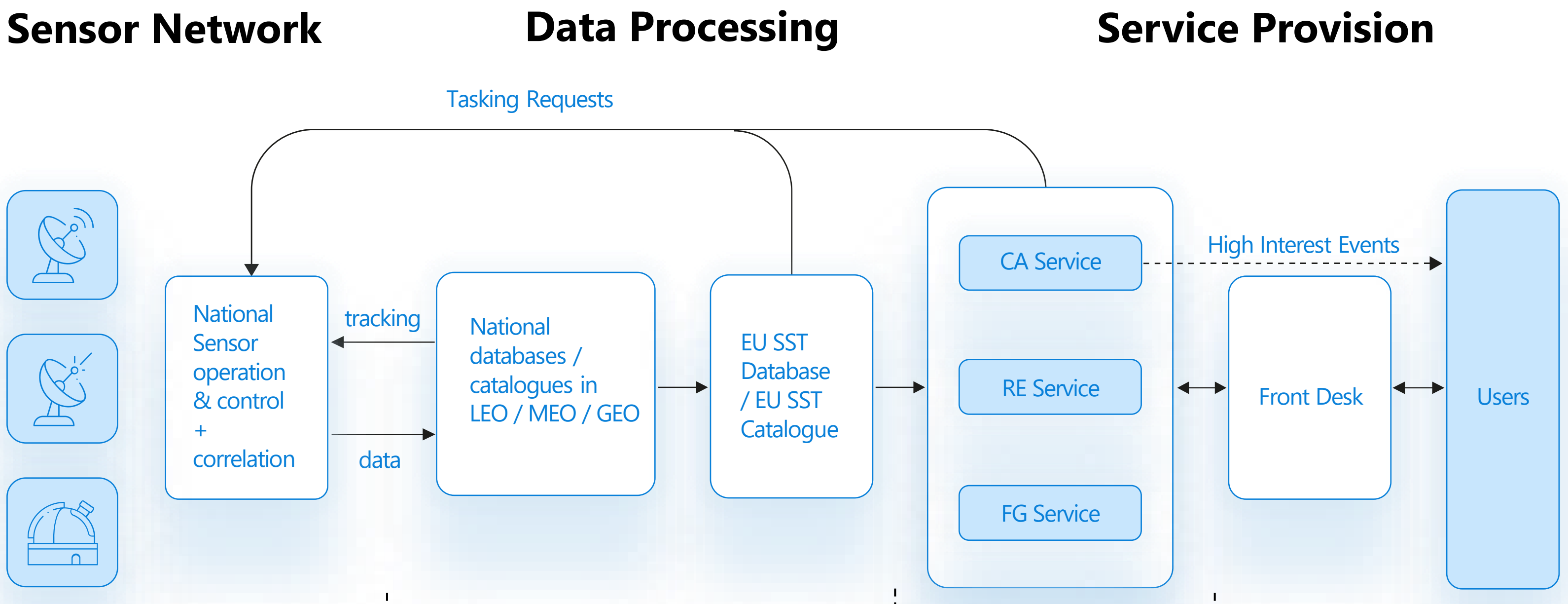
*EU SST sensors network (2023)*

# Building an SST scenario: outline

**Real World**



Synthetic population generated for a SST scenario (illustration with CNES VTS)




**Reference setup**

what objects are we interested in?

**Sensor layer**

how do we observe these objects?

**Data processing layer**

what knowledge do we acquire about these objects?

**Service provision layer**

what do we do with that information?

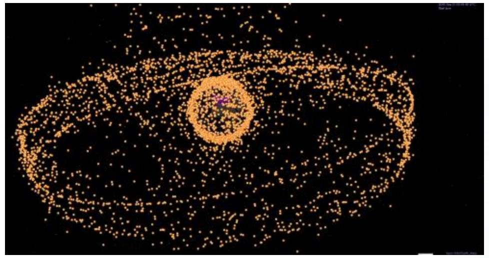
**Performance evaluation**

how well did we deliver?

**Simulation test bench**

# Building an SST scenario: outline

**Real World** | **Sensor Network** | **Data Processing** | **Service Provision**



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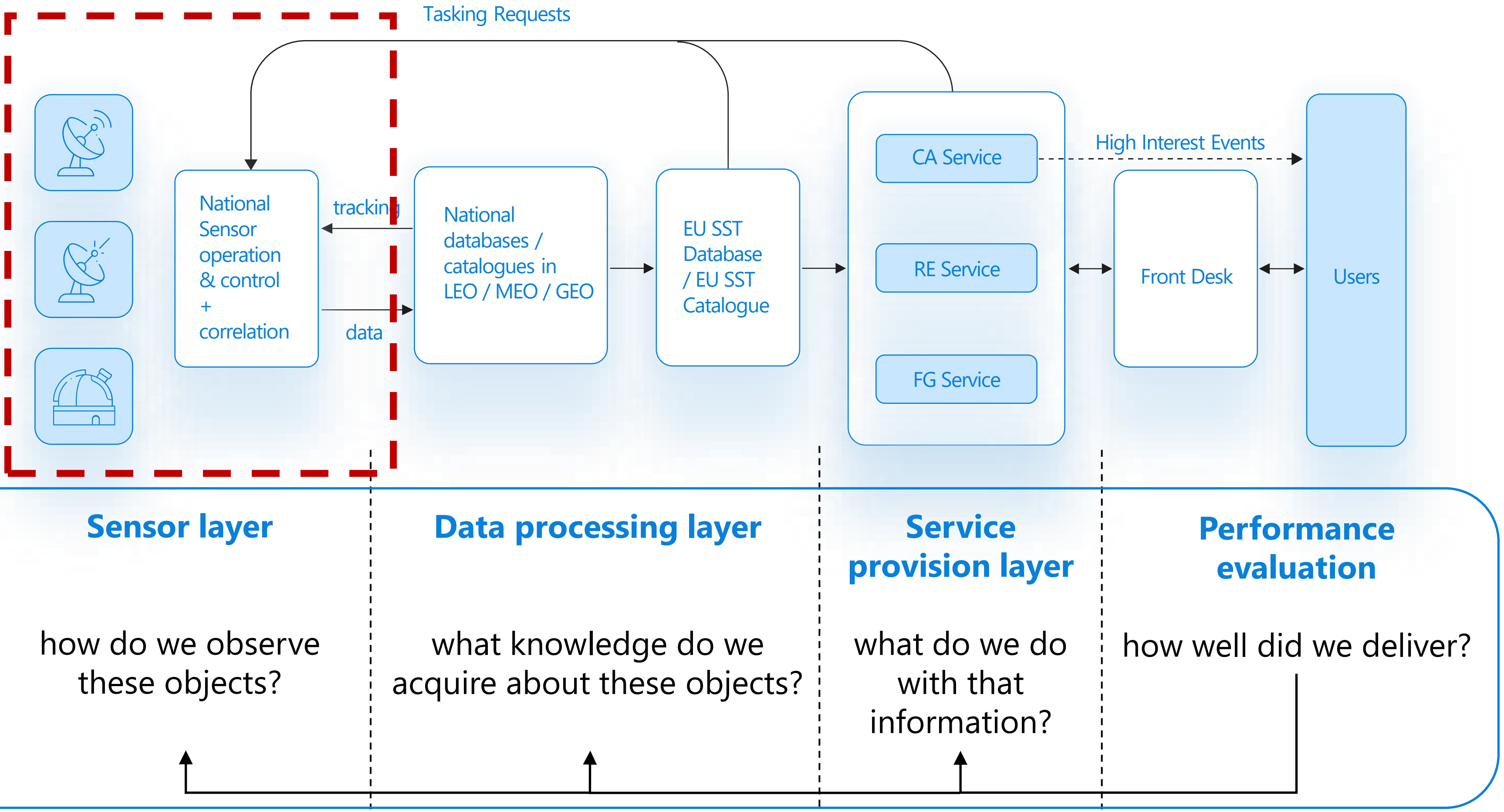
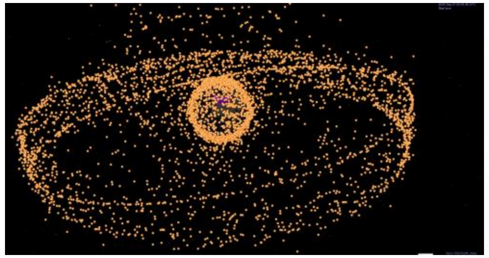



**Simulation test bench**

J.M. Hermoso *et al.* "System Approach to Analyze the Performance of the EU Space Surveillance and Tracking system", *Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS)*, 2021

# Building an SST scenario: outline

**Real World** | **Sensor Network** | **Data Processing** | **Service Provision**



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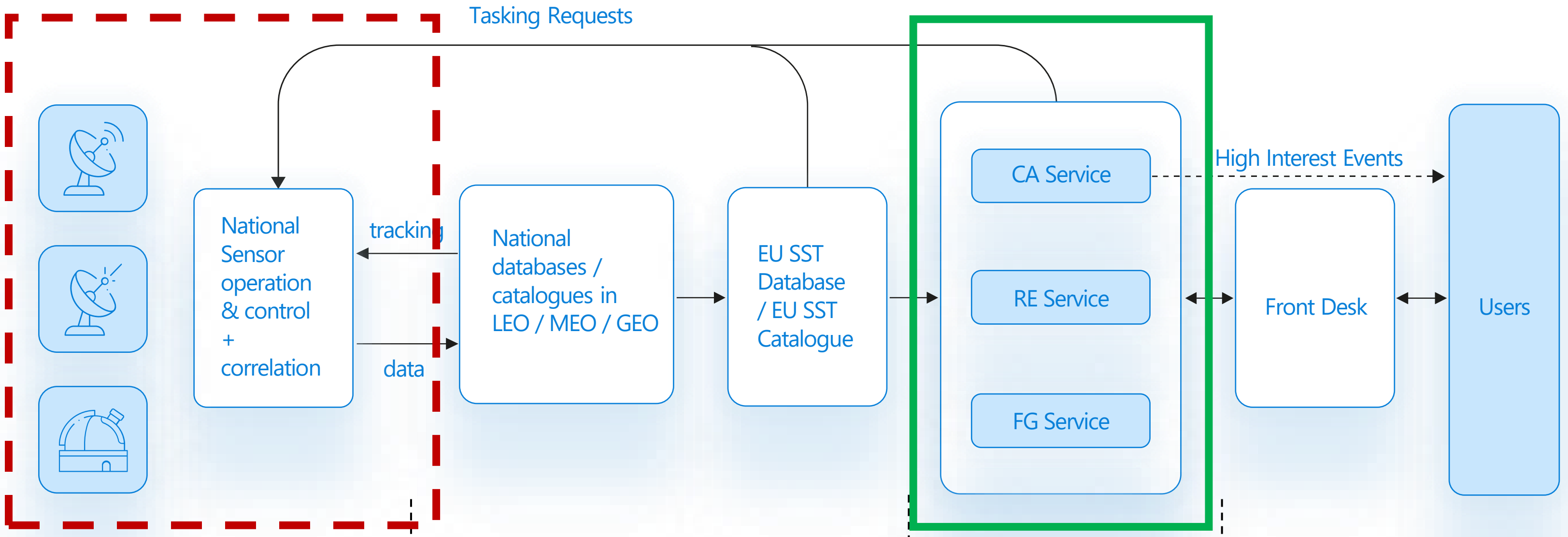



| **Reference setup** | **Sensor layer** | **Data processing layer** | **Service provision layer** | **Performance evaluation** |
|---|---|---|---|---|
| what objects are we interested in? | how do we observe these objects? | what knowledge do we acquire about these objects? | what do we do with that information? | how well did we deliver? |

## Simulation test bench

J.M. Hermoso *et al.* "System Approach to Analyze the Performance of the EU Space Surveillance and Tracking system", *Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS)*, 2021

# Simulation test benches: challenges and features

- **Robustness and validity**: Two independent test benches: AS4/*Ssasim* (DEIMOS/GMV) & BAS3E (CNES)

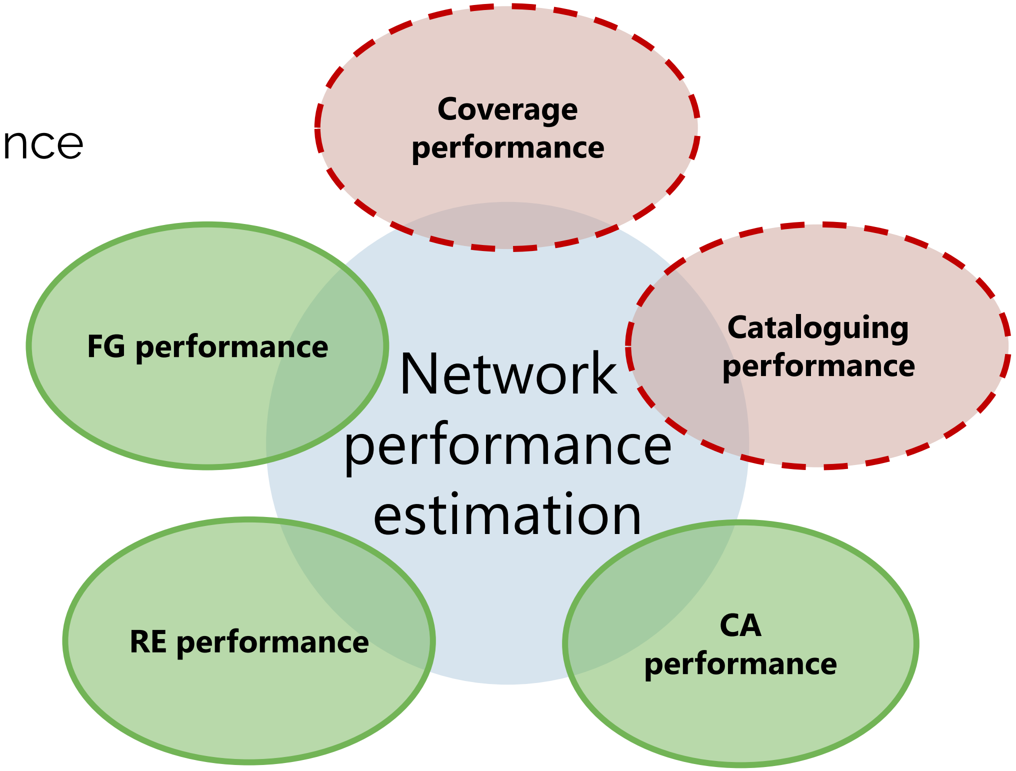
- **Population design** shaped by scenario specifics:
  - *Relevant* to analysis at hand: (near-)collisions are needed for CA studies
  - *Representative* of real population, to derive meaningful statistics
    - historical/available data (e.g. SpaceTrack, ESA MASTER populations) exploited when relevant
  - *Suitable* for simulations under limited computational resources
- **Orbital propagation** accounts for modelling mismatches in operational conditions:

| Simulation Tool | Force model for reference population | Force model for catalogued population |
|---|---|---|
| AS4/SSASIM | WGS84 Earth model with 12x12 development<br>Drag: atmospheric model Jacchia Lineberry with constant solar activity (F10.7 = 140 sfu and Ap = 9)<br>3rd body perturbation (Sun and Moon)<br>Solar Radiation Pressure with Earth eclipses | WGS84 Earth model with 12x12 development<br>Drag: atmospheric model MISISE90<br>3rd body perturbation (Sun and Moon)<br>Solar Radiation Pressure with Earth eclipses |
| BAS3E | WGS84 Earth model with 12x12 development<br>Drag: atmospheric model MSIS00 with constant solar activity (F10.7 = 140 sfu and Ap = 9)<br>3rd body perturbation (Sun and Moon)<br>Solar Radiation Pressure with Earth eclipses | WGS84 Earth model with 12x12 development<br>Drag: atmospheric model DTM<br>3rd body perturbation (Sun and Moon)<br>Solar Radiation Pressure with Earth eclipses |

# The five pillars of performance evaluation

- **Inter-dependent** features affecting overall performance
- Strong **focus on end-user**'s perspective
- **Coverage performance** consist in evaluating the measurements that would be provided by the network and perform statistical analysis.
- **Cataloguing performance** consist in evaluating the capacity of the system to build and maintaining a catalog of orbit.

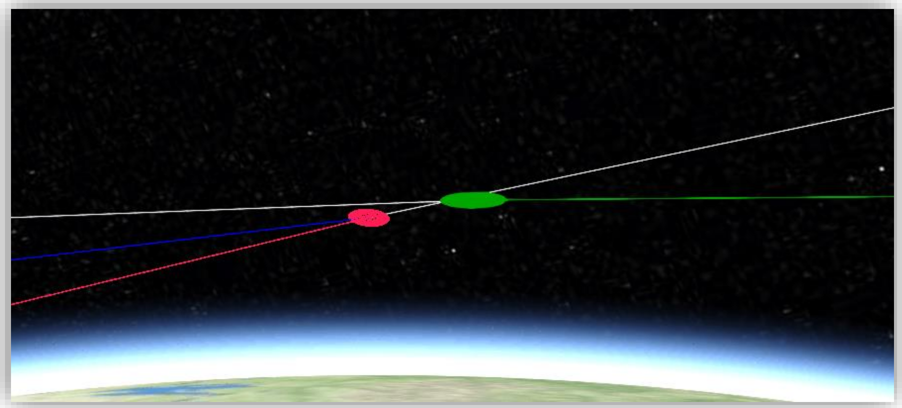
J.M. Hermoso *et al., AMOS*, 2021
V. Morand *et al., IAC*, 2021



# CA Performance

- **Collision Avoidance evaluation of performance** centers on
  - The capacity of the system to detect a conjunction
  - Once detected, the system capacity to follow the event and provide extra measurement
  - Assessment of the added value of the system
  - The global performance of the system to reduce the risk for on-orbit satellites

- Methodology based on the **comparison of true conjunctions and detected conjunctions**
  - Comparison of TCA, missed distance
  - Computation of the Probability of Collision (PoC)



- Main **challenges**
  - *Build* a reference population of colliding objects
  - *Control* conjunction number, TCAs and missed distances
  - *Maintain* realistic geometry of conjunction

# CA Assumptions and Results

- Generation of **synthetic population for CA**:
  - Primary object propagated until random TCA
  - Secondary object created at TCA with random MD distribution tuned
  - Secondary relative position and velocity selected from a historical dataset of CDMs.

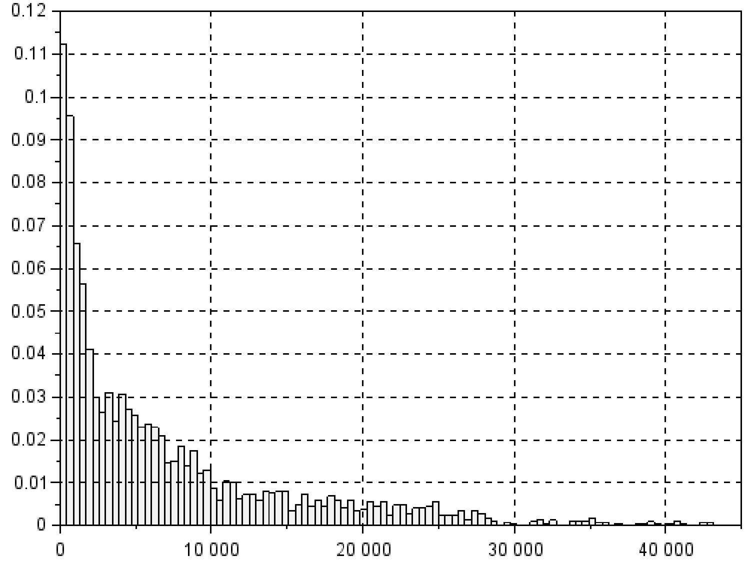
- **CA event** characterization:
  - Conjunction screening with JSPOC safety volume, MD and TCA at local minima
  - Computation of penetration factor ($P_f$)

    *if* $P_f > 0 \Rightarrow$ *TCA*
  - PoC computed with *'KsKp method'* :

    $C = K_p C_p + K_s C_s$ $K_p$, $K_s \in [0.25,4]$; 16 steps

    $ScaledPoC = \max(PoC)_{Kp,Ks}$

MD (m) histogram for **LEO synthetic population** (2500 pair of objects, >3000 conjunctions)

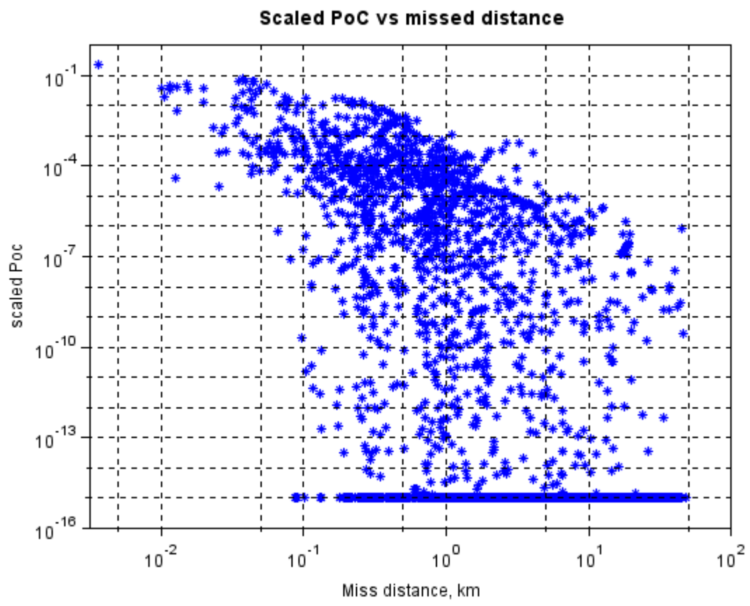


# CA Assumptions and Results

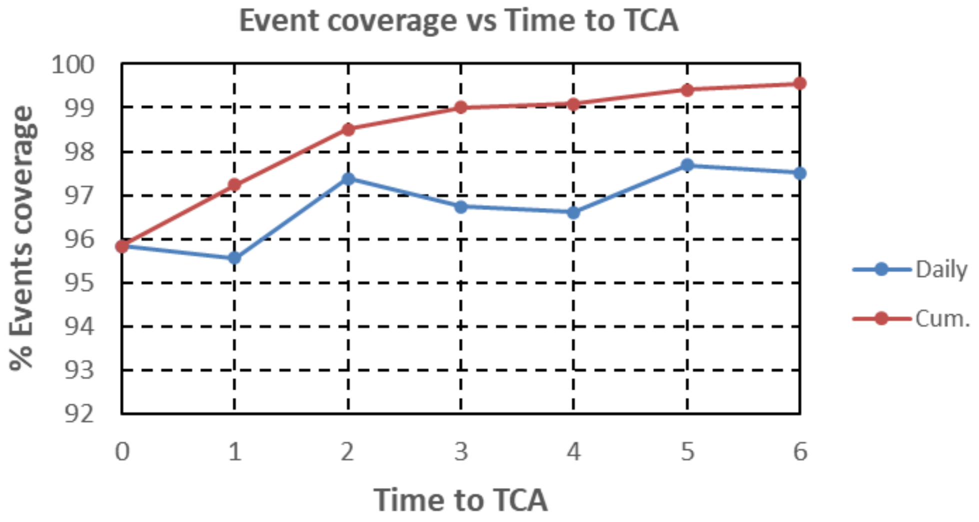
- LEO CA event (2500 pair of objects, 7 days):

| | Percentage of event followed (survey network) | | |
|---|---|---|---|
| **Secondary size** | SMALL | MEDIUM | LARGE |
| **Observed** | 10 | 79 | 98 |

SMALL, RCS < $0.1m^2$; MEDIUM, 0.1 < RCS < $1.0m^2$; and LARGE, RCS >$1.0m^2$




- GEO CA event (2210 pair of objects, 7 days):

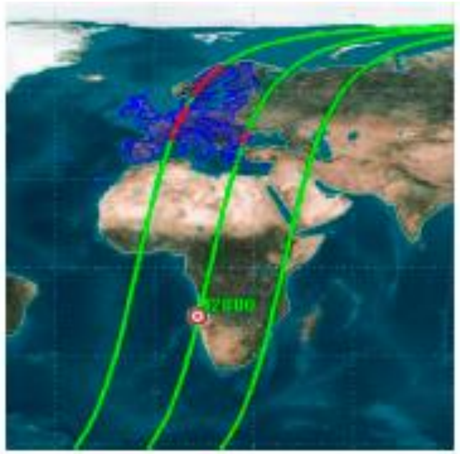


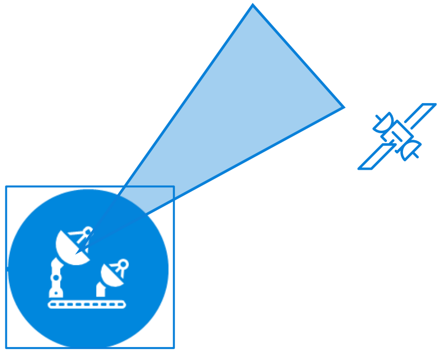
# RE Performance

- **Atmospheric re-entry analysis performance** focuses on
  - The ability to detect and follow the re-entry during the last days and hours prior re-entry
  - The ability to forecast the re-entry epoch and location

- Methodology based on the comparison of **true re-entry and predicted re-entry**

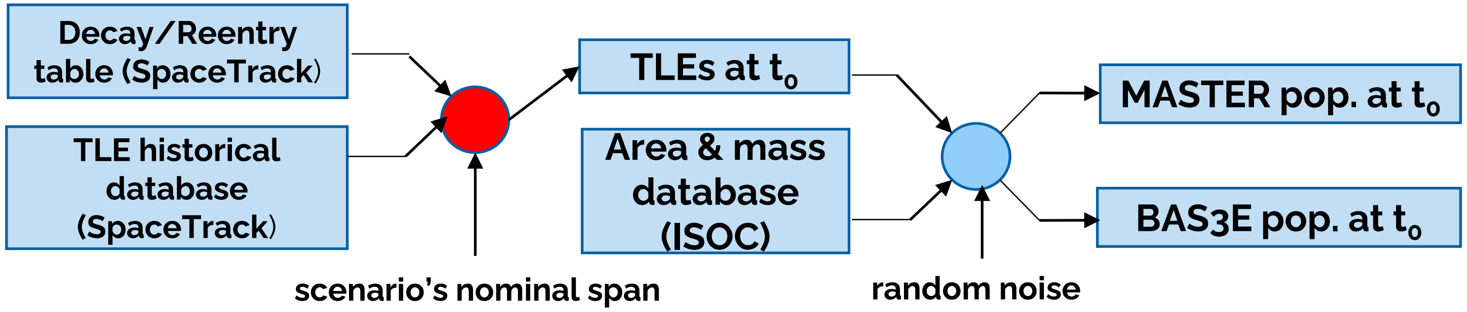
- **Main challenges** are
  - *Build* a reference population of re-entering objects
  - *Mitigate* model uncertainties in shaping true re-entry epochs
  - *Integrate* tracking sensors, *implement* “no-show” events

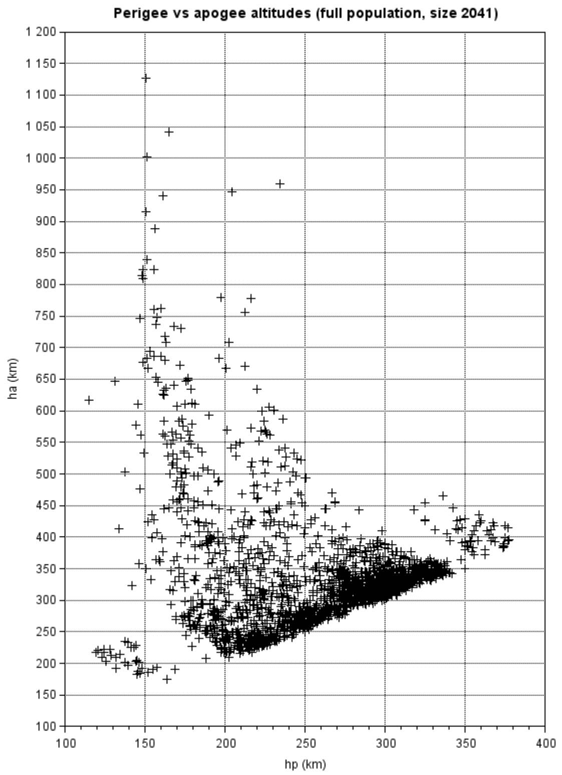




# RE Assumptions and Results

- **Reference population:**
  - Every object re-enters the atmosphere within the 15-day-long span
  - 2000 historical RE event from SpaceTrack
  - Using BAS3E's each object propagated until RE point (80 km), back-propagated, dispersed and averaged on 12 days
    - **1559 SATs & DEBs and 482 R/Bs**




- Current focus on daily coverage statistics in the last days of orbital lifetime:

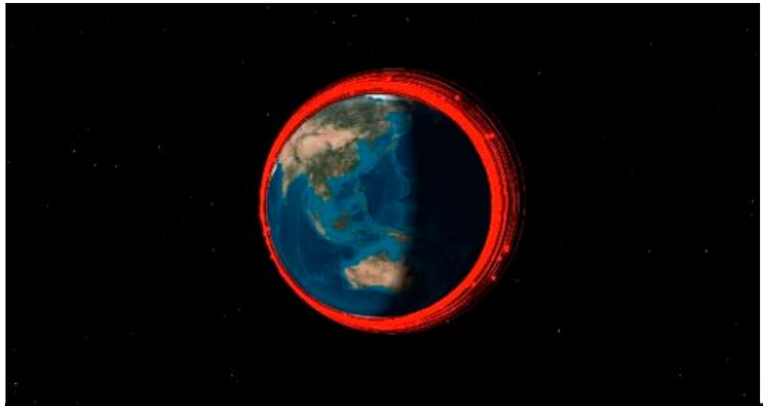
| | Percentage of observed objects, on a daily basis, until re-entry | | | | | | |
|---|---|---|---|---|---|---|---|
| **Survey and tracking radars** | RE - 6d | RE- 5d | RE - 4d | RE - 3d | RE - 2d | RE - 1d | RE |
| | 98 | 97 | 97 | 97 | 97 | 96 | 71 |

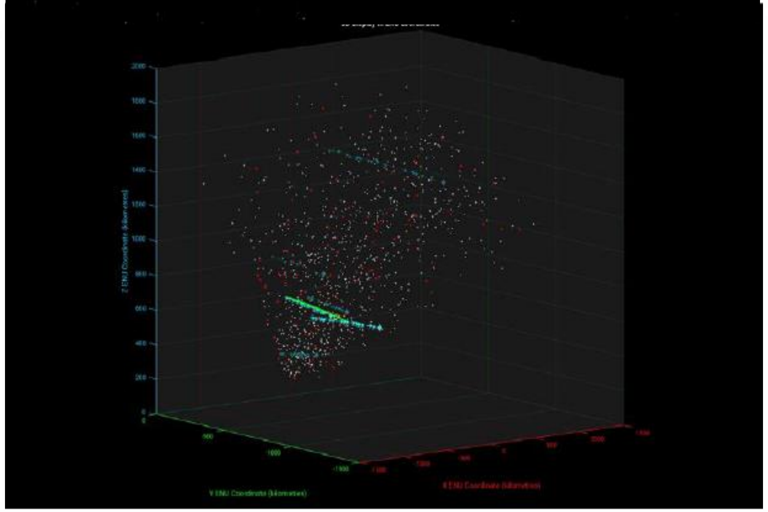
# FG Performance

- **Fragmentation analysis performance** consists in evaluating
  - The capacity to detect a fragmentation : timeliness, identification of parent object(s)
  - The capacity to track and catalogue as many fragments as possible

- Methodology based on the use of **simulated fragmentation with known properties**
  - Parent(s) body and orbit
  - Repartition of the fragments in terms of mass, area, orbit

- **Main challenges:**
  - *Model* measurement process when observing a cloud
  - *Handle* data-to-object observation in dense environments
  - *Perform* Initial Orbit Determination (IOD) upon debris detection



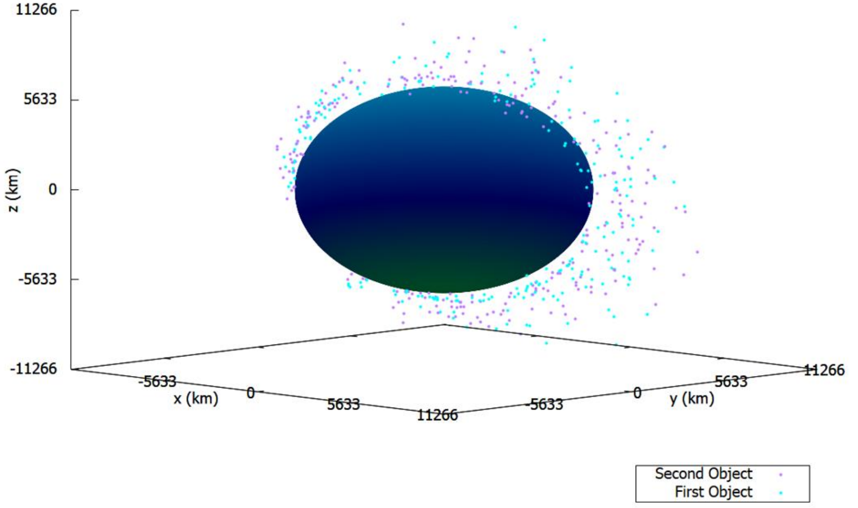


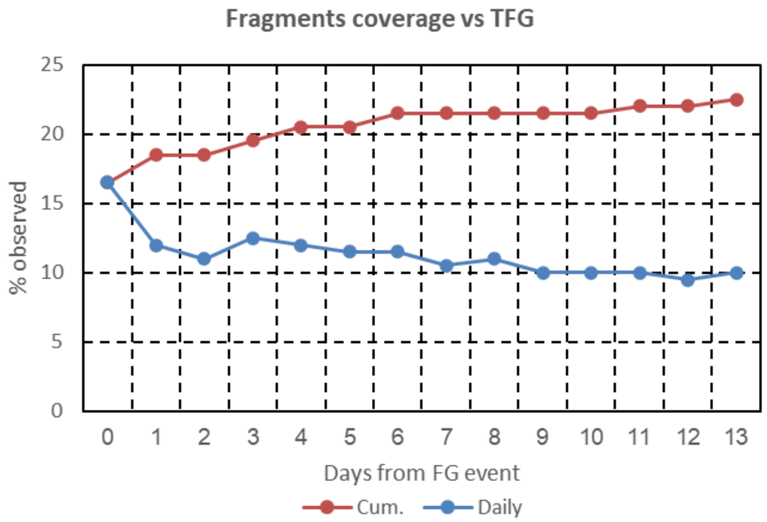
# FG Assumptions and Results

- Generation of **population of fragments**:
  - Analysis historical event
  - Fragmentation Generation tool (AS4)
  - MASTER 2009 NASA Breakup Model

| FG synthetic population characterization | | | |
|---|---|---|---|
| **Orbital Regime** | LEO | MEO | GEO |
| **FG event type** | Collision at 800 km | Explosion | Explosion |
| **Parent(s)** | 1190 kg<br>500 kg | ~2000 kg NSO<br>~2000 kg HEO | ~2000kg |

- LEO FG event (2459 objects >= 7cm, 14 days):



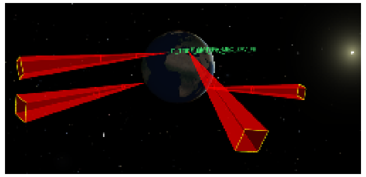




| Percentage of event followed (survey network) | | |
|---|---|---|
| SMALL | MEDIUM | LARGE |
| 17 | 98 | 100 |

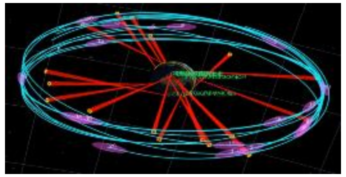
# Conclusions

- System engineering tool evolution towards **service provision** to evaluate the performance of current and future **EU SST network**

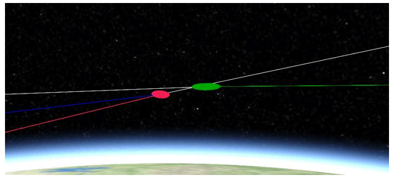
- **Multi-layered performance evaluation**, reflecting five features of SST operational needs



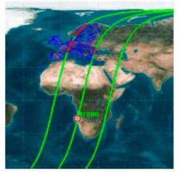
Coverage



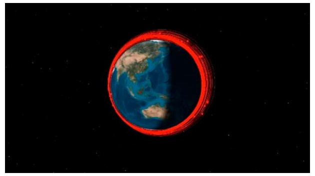
Cataloguing



Collision avoidance



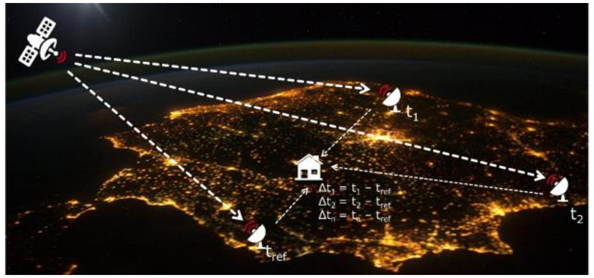
Re-entry analysis



Fragmentation analysis

- Quantitative analysis of projected sensor networks, **supporting decision makers into shaping the future of EU SST**

- Future update for integration of new sensors:
  - Space-based sensors
  - Infrared sensors
  - Passive RF sensors



See Virtual Poster:
**PR solution design to improve CA services**

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