3rd EU SST Webinar: Building the future of SST

5 October 2021 – 14h CET

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 952852, No 785257, No 760459, 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. This message 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.

3rd EU SST Webinar

Building the future of SST

Speakers

Rodolphe MUÑOZ
(EC – DG DEFIS)

Pascal FAUCHER
(SST Cooperation)

Marc BECKER
(SST Cooperation)

Emmanuel DELANDE
(SST Cooperation)

Konrad BOJAR
(SST Cooperation)

Christoph REISING
(Fraunhofer FHR)

Emilio José VIEDMA
(Indra)

Speakers

- Vincent MORAND (SST Cooperation)

- Baptiste GUILLOT (SAFRAN)

- Francesco CERUTTI (OHB)

- Francisco Javier SIMARRO (GMV)

- Romain LUCKEN (Share My Space)

- Joris OLYMPIO (Airbus Defence and Space)

Agenda

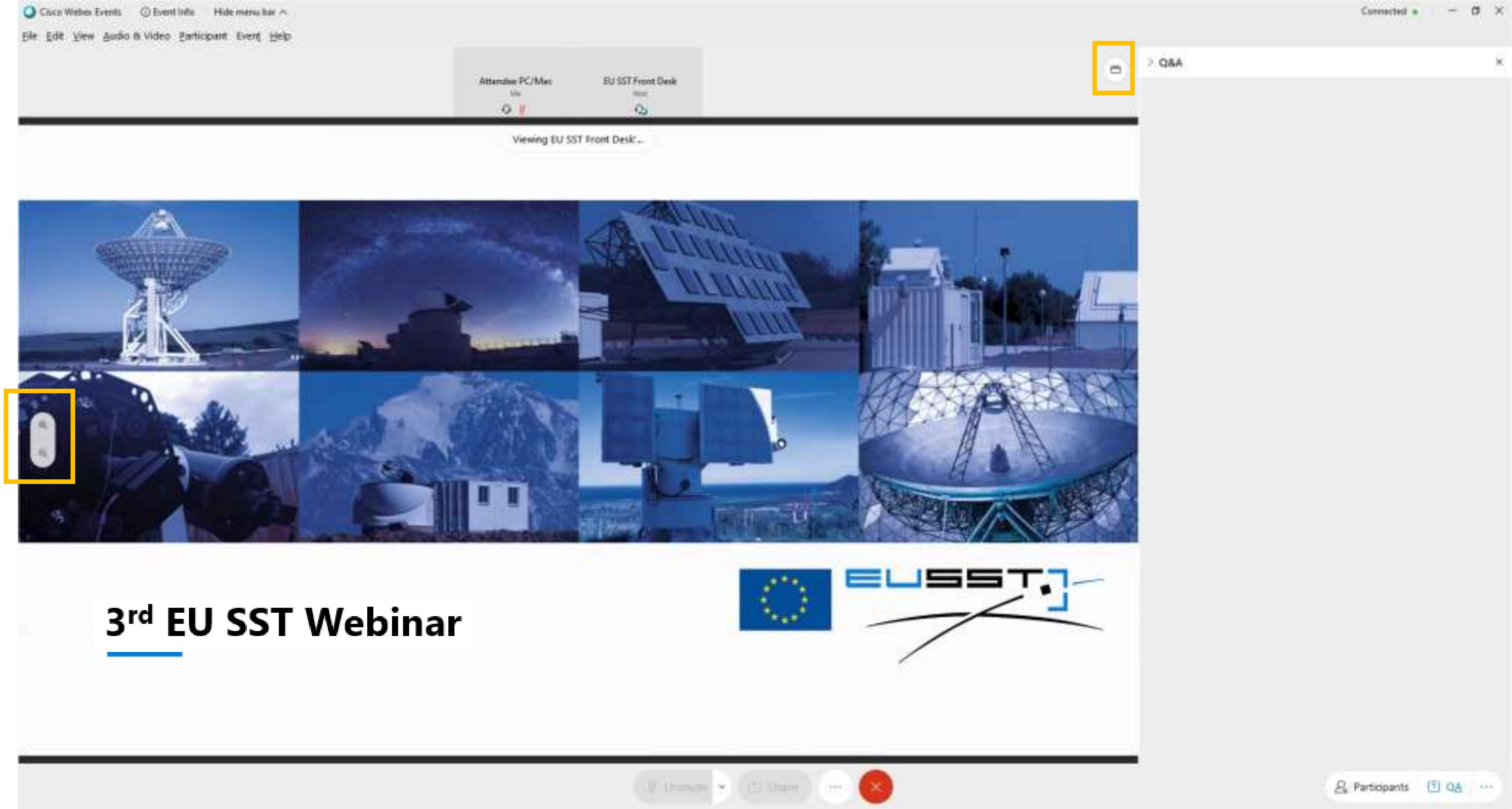
- **14:00 – 14:10 Welcome** [Moderator: Ms Theodora Filip (SatCen)]
- **14:10 – 14:30 SST Context**
  - **Introduction** [EC – DG DEFIS: Mr Rodolphe Muñoz]
  - **EU SST overview** [SST Cooperation Chair: Dr Pascal Faucher]
  - **Future trends on SST** [SST Cooperation: Mr Marc Becker]
- **14:30 – 14:55 EU SST Architecture studies** [SST Cooperation: Dr Emmanuel Delande]
- **14:55 – 15:20 EU SST Capability development: sensor upgrades in the context of EU SST**
  - **EU SST Intro** [SST Cooperation: Mr Konrad Bojar]
  - **GESTRA EU SST** [Fraunhofer FHR: Mr Christoph Reising]
  - **S3TSR** [Indra: Mr Emilio José Viedma]
- **15:20 – 15:30 Break**
- **15:30 – 16:50 EU SST R&D Activities**
  - **Studies on sensors** [SST Cooperation: Mr Vincent Morand; SAFRAN: Mr Baptiste Guillot; OHB: Dr Francesco Cerutti]
  - **Studies on data processing** [SST Cooperation: Mr Vincent Morand; GMV: Mr Francisco Javier Simarro]
  - **Studies on service provision** [SST Cooperation: Mr Vincent Morand; Share My Space: Dr Romain Lucken; Airbus Defence and Space: Dr Joris Olympio]
- **16:50 -17:00 Conclusions and closure**

Platform & Interaction mechanisms

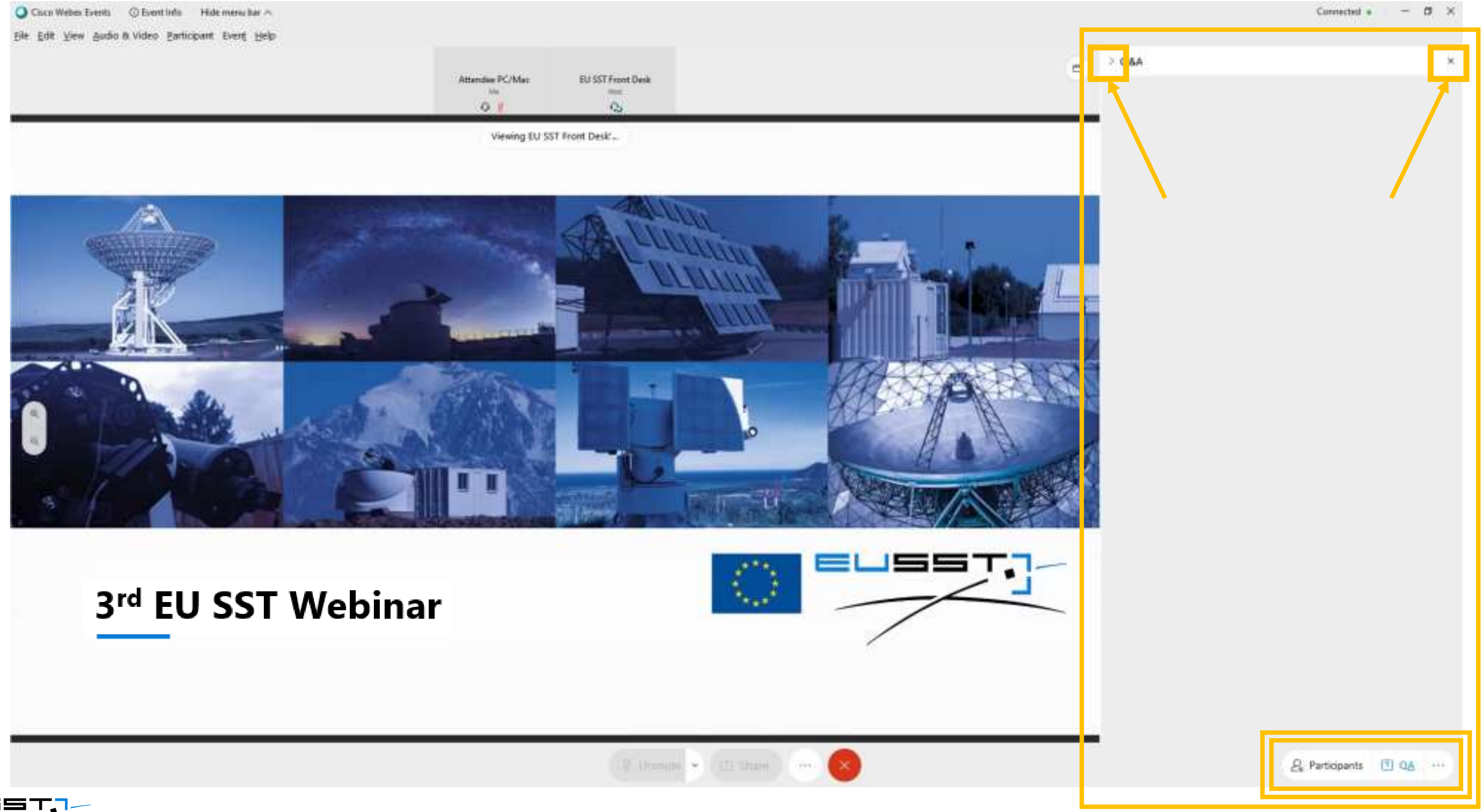
Virtual environment

- Webex Events platform
- Twitter: **@EU_SST #EUSST #EUSSTWebinar**
- Email: sst.info@satcen.europa.eu

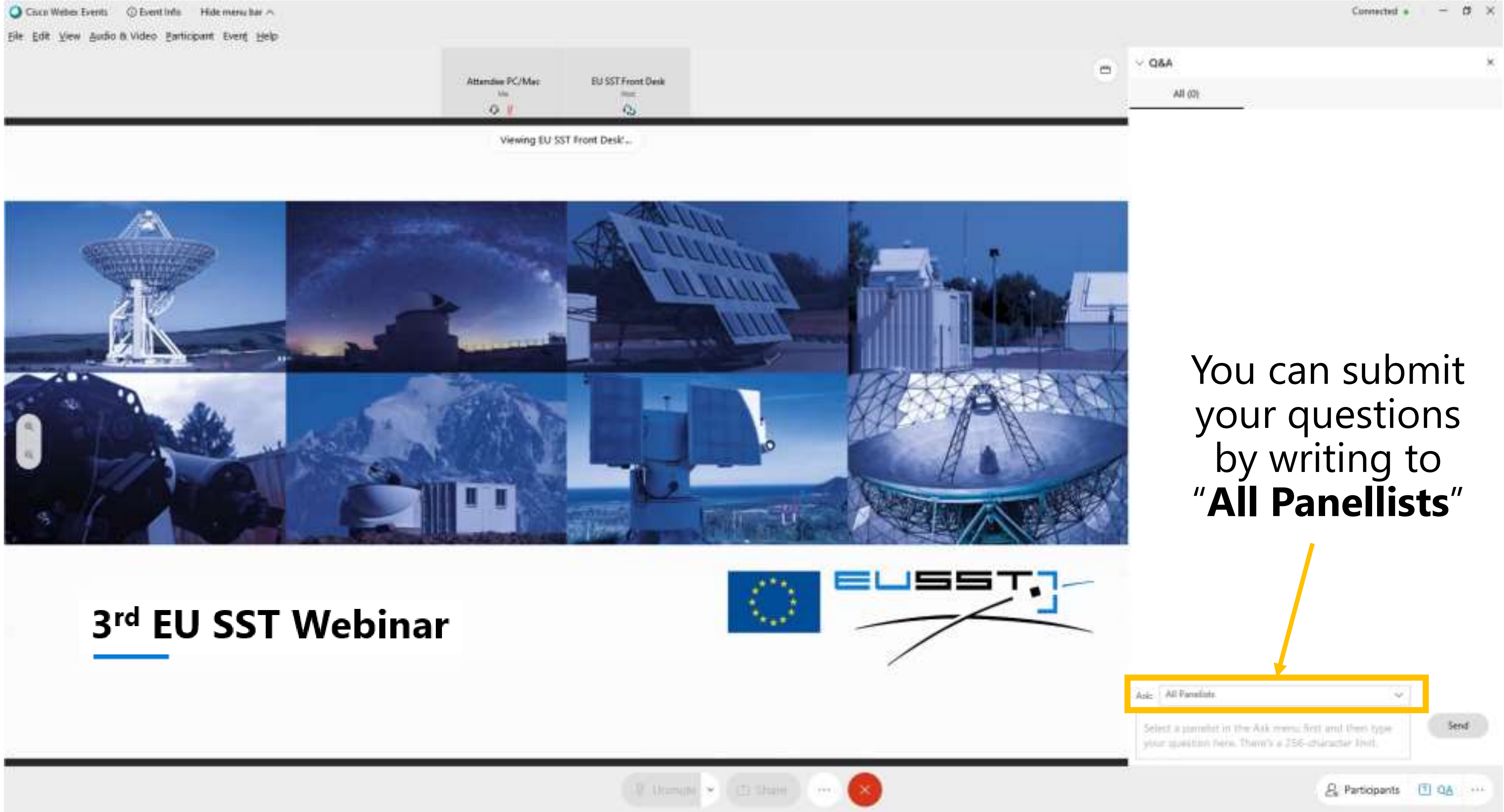
Webex Events: Dashboard setup



Webex Events: Panels

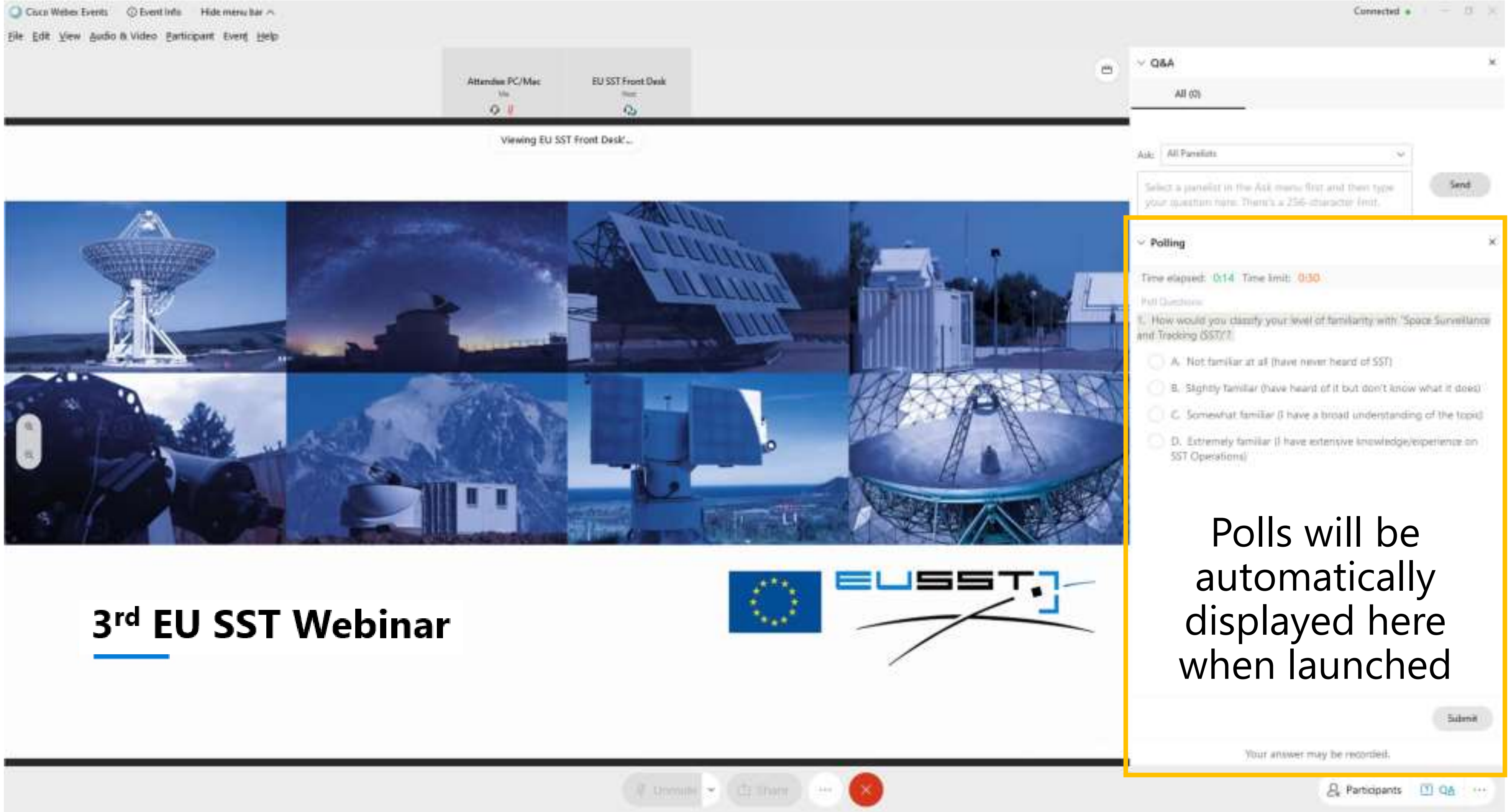


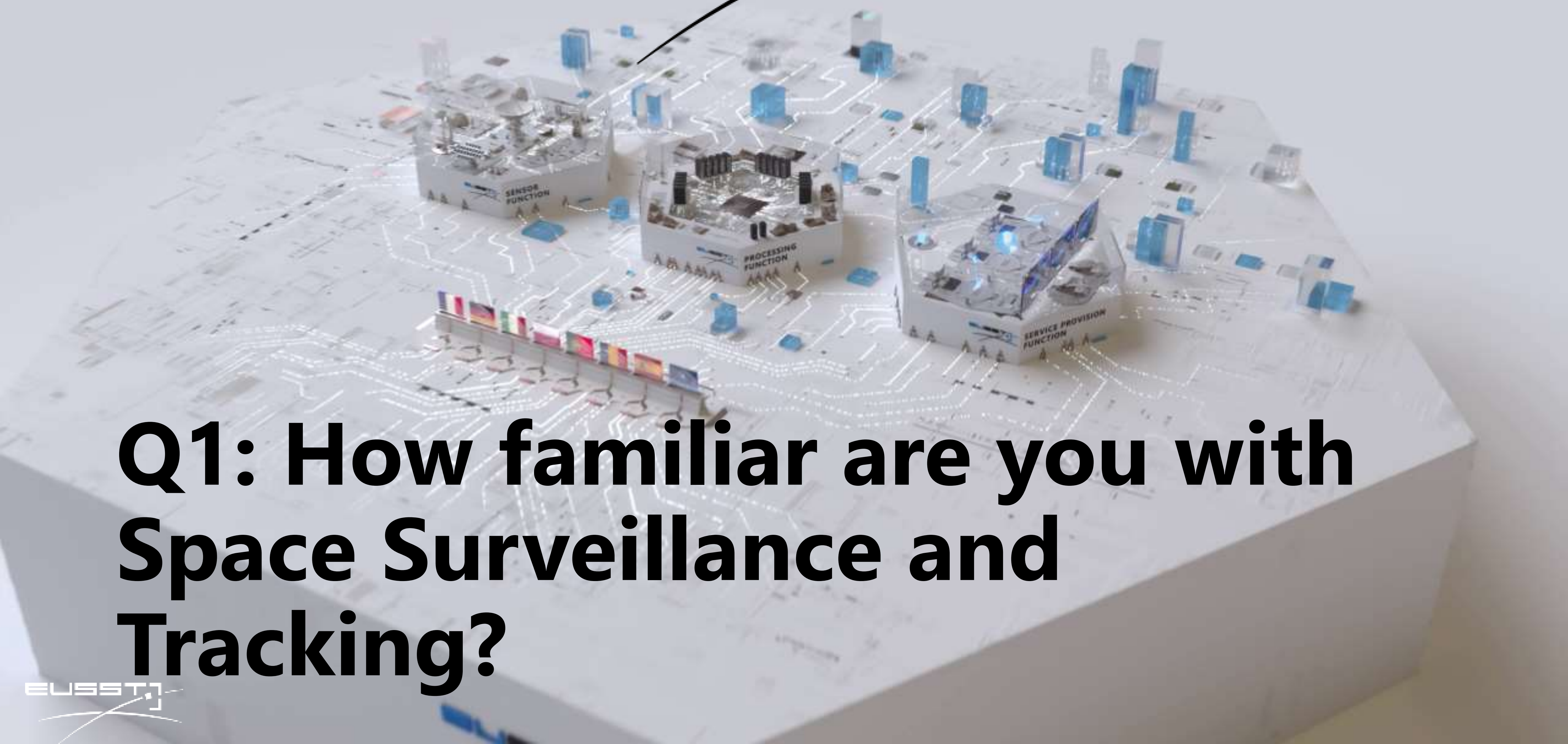
Webex Events: Q&A



You can submit your questions by writing to "**All Panellists**"

Webex Events: Polling





Q1: How familiar are you with Space Surveillance and Tracking?

SST Context: Introduction

Rodolphe Muñoz, European Commission

5 October 2021

EU SST Introduction

EU SST: A unique set-up

- Based on Member States capacities
- With the strong support of EU industries

EU SST: Operational success

- Constant increase of users
- Nearly all European actors

EU SST and the Space Regulation: A new turning point

- The development of new services
- The creation of the Partnership
- The opening up to third countries' users

EU SST Introduction

- **The aim of the 3rd EU SST Webinar: Present the future of EU SST**
  - EU SST Architecture studies
  - EU SST Capability development
  - EU SST R&D activities

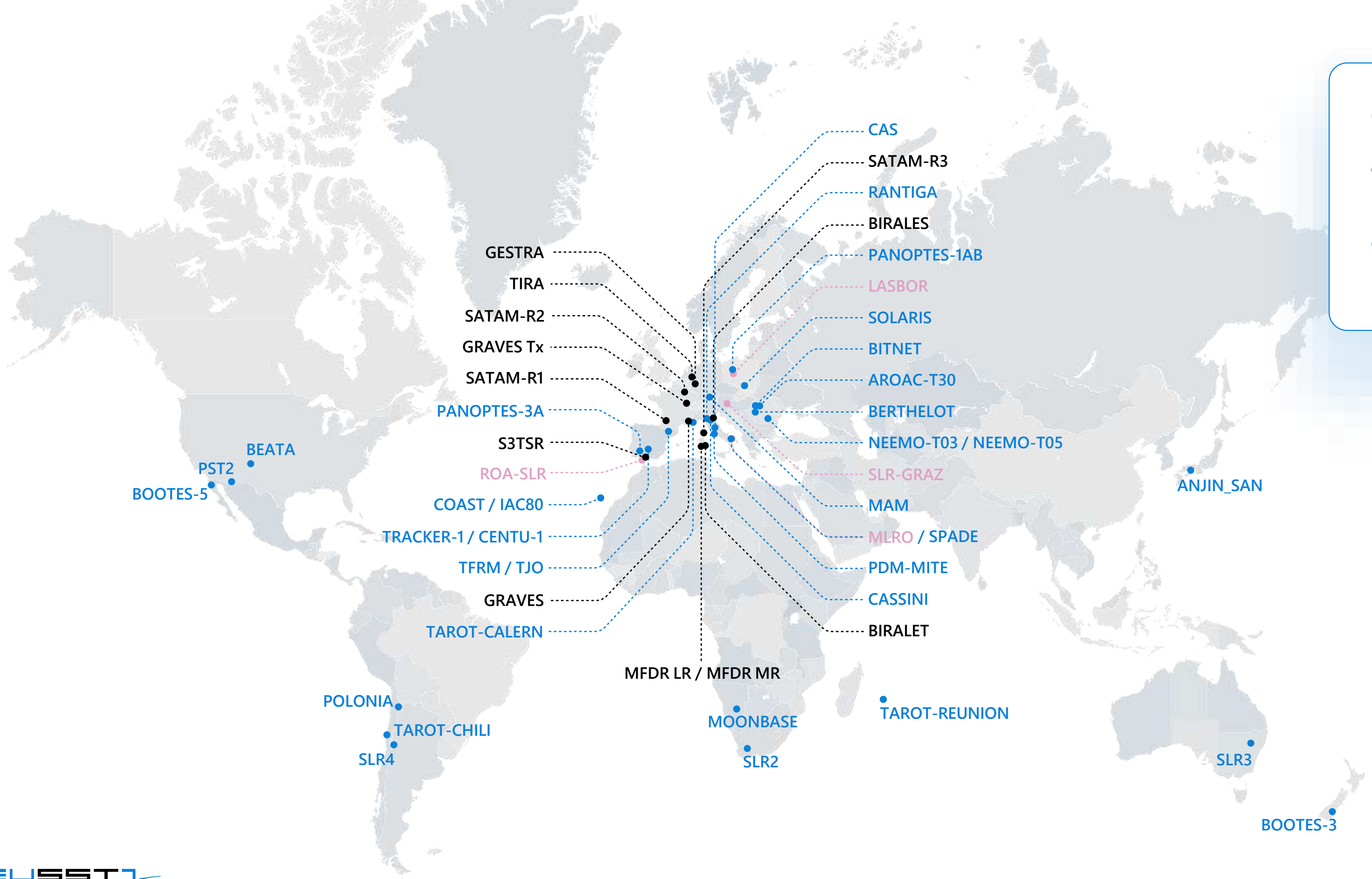
- **EU SST and EU autonomy**
  - A certain level of autonomy
  - “Space Surveillance and Tracking is the precursor of the European Space Traffic Management system”

SST Context: EU SST overview

Dr Pascal Faucher, Chair of the SST Cooperation

5 October 2021

Sensors



- 4 Lasers
- **11 Radars** (3 surveillance, 8 tracking)
- **34 Telescopes** (18 surveillance, 16 tracking)

Satellites

247 Satellites

LEO

78

BIROS
SAR-LUPE 1, 2, 3, 4, 5
TET-1
TANDEM-X
TERRASAR-X
REAKTOR HW, Sunstorm, W-CUBE
DEIMOS 1, 2
METOP A, B, C
SENTINEL 1A, 1B, 2A, 2B, 3A, 3B, 5P, 6A
PAZ
UPMSat-2
ION-SCV 1, 2, 3
CHEOPS
TRISAT
Brik-II
NEPT-1
GomX-4A. 4B

ELISA E12, E24, W11, W23
HELIOS 2A, 2B
VENμS
CSO-1, 2
CALIPSO
JASON 3
PLEIADES 1A, 1B
SMOS
BRITE PL-1,PL-2
EYESAT
ANGELS
CERES 1,2,3
ELO3
XR-1, ICEYE-X9, X8, X7, X6, X5 , X4, X2, X1, X11, X12, X13, X15
GMS-T, Odin
NETSAT-1,2,3,4
Pleiades NEO 4

MEO

48

GSAT / Galileo
0101, 0102, 0103, 0104, 0201, 0202, 0203, 0204, 0205, 0206, 0208, 0209, 0210, 0211, 0207, 0212, 0213, 0214, 0215, 0216, 0217, 0218, 0219, 0220, 0221, 0222, 0223, 0224

O3B PFM, O3B FM 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20

GEO

121

COMSATBW-1, 2
SICRAL 1, 1B, 2
XTAR-EUR
SPAINSAT
METEOSAT-8, 9, 10, 11
HYLAS 1, 2, 4
ASTRA 1D, 1KR, 1L, 1M, 1N, 1G, 2A, 2C, 2D, 2E, 2F, 2G, 3A,,3B, 5B
AMC 1, 3, 4, 6, 8, 11, 15, 18, 21
SES 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11,12, 14, 15 , 16/Govsat-1, 17
NSS 5, 6, 7, 9, 10, 11, 12
SIRIUS 4, QUETZSAT 1, CIEL 2

ATHENA-FIDUS
SYRACUSE 3A, 3B, 4A
HELLAS-SAT 2, 3, 4
INMARSAT 3F1, 3F2, 3F3, 3F5, 4F1, 4F2, 4F3, AF1, 5F1, 5F2, 5F3, 5F4, GX5
EUTELSAT 10A, 16A, 172A, 21B, 25B, 28A, 28B, 36A, 36B, 3B, 5WA, 65W, 7WA, 70B, 7A, 7B, 8WB, 9A, 9B, HB 13B, 13C, 13D, KASAT 9A, 12WB, 172B, 7C, 5 WEST B, Konnect, Quantum
AMAZONAS 2, 3, 5, HISPASAT 30W-5, 30W-6, 36W-1, 74W-1, 143W-1
BULGARIASAT-1

Commercial 150 **Govern./IGOs** 62 **Military** 29 **Universities / Research** 6

Updated as of 01/10/2021

Our strategic objectives

1. Ensure the protection and resilience of space infrastructures, including European Union flagships Galileo and Copernicus
2. Deliver high quality SST operational services to improve space traffic coordination and ensure safe space operations
3. Perform research and innovation, and development of capabilities to achieve a higher level of **strategic autonomy** in Europe
4. In turn contribute to global burden-sharing in the SSA domain and act as a reliable and capable partner in the international arena
5. Foster the innovation in the SSA domain, support the **competitiveness of entrepreneurs, start-ups and the EU downstream space industry**

We shall ensure that European competitiveness contributes to build a higher level of European strategic autonomy in the SSA domain

Increasing budgetary efforts in R&D and capabilities development

- In MFF 2014-2020, 65% of the overall budgetary effort in 2016-2022 is dedicated to R&D and capabilities development
- The budget subcontracted to the **European industry** in R&D and capabilities is constantly growing very much over the years:
  - Increase of +205% in 2020-2022 compared to 2018-2019
  - 75% of the overall budget is subcontracted to industry in 2016-2022 (6,5 years) and recently nearly 80% in 2020-2022 (3 years)

R&D and capabilities	**Subcontracts**
2018-2019 vs 2016-2017	**+63%**
2020-2022 vs 2018-2019	**+205%**

- In MFF 2021-2027, we foresee again an important budget increase for R&D and development of capabilities in Europe
- We will soon establish a European Industry and Start-up Forum (EISF) to foster innovation and competitiveness of **entrepreneurs, start-ups and the EU downstream space industry**

SST Context:
Future trends in SST

Marc Becker, SST Cooperation

5 October 2021

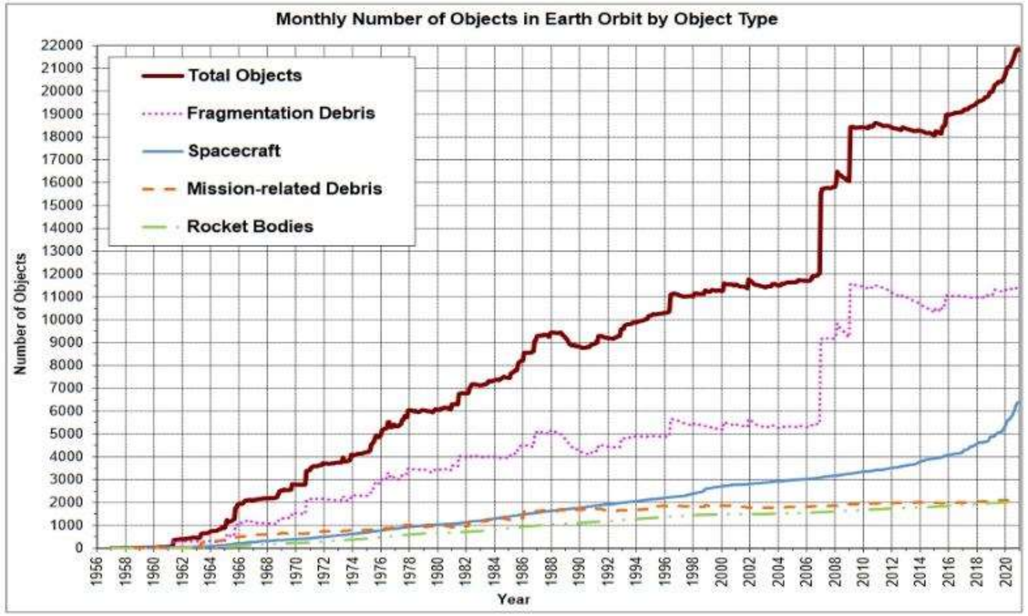
Foresight activities in EU SST

- The **space environment** is undergoing **paradigmatic changes**: highly dynamic and complex evolution of the technological, policy, regulatory and operational context of SSA, SST and STM
- **Horizon Scanning** as a dedicated foresight activity in EU SST to identify, observe and understand current and emerging developments
- Findings inform **EU SST's R&D activities** to prepare the future and support strategic discussions

Current and future trends

A rapidly changing space environment:

- Continuous growth in the use of space since the end of the Cold War
- More than 30,000 debris objects >10cm, more than 900,000 debris objects >1cm
- More than 4,000 active satellites are currently orbiting Earth; their number has more than doubled since 2015
- With the growing number of space objects, there is an increased risk of unintended collisions that can lead to the creation of debris

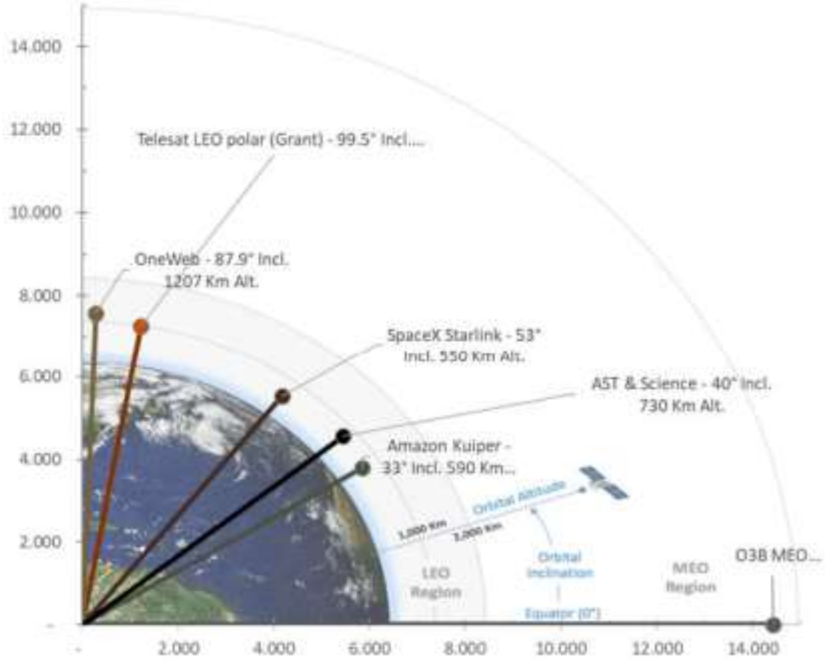


Source: NASA

Current and future trends

New Space and large constellations:

- New Space: Trends of miniaturisation, commercialisation, falling costs
- SpaceX became the world's largest satellite operator with more than 1,600 satellites of its Starlink constellation currently in LEO
- Similar plans from OneWeb, Kuiper etc. plus non-Western entities
- Monitoring deployment (S/C numbers, orbital altitude, manoeuvrability etc.) relevant for EU SST architecture studies & evolution of the SST services



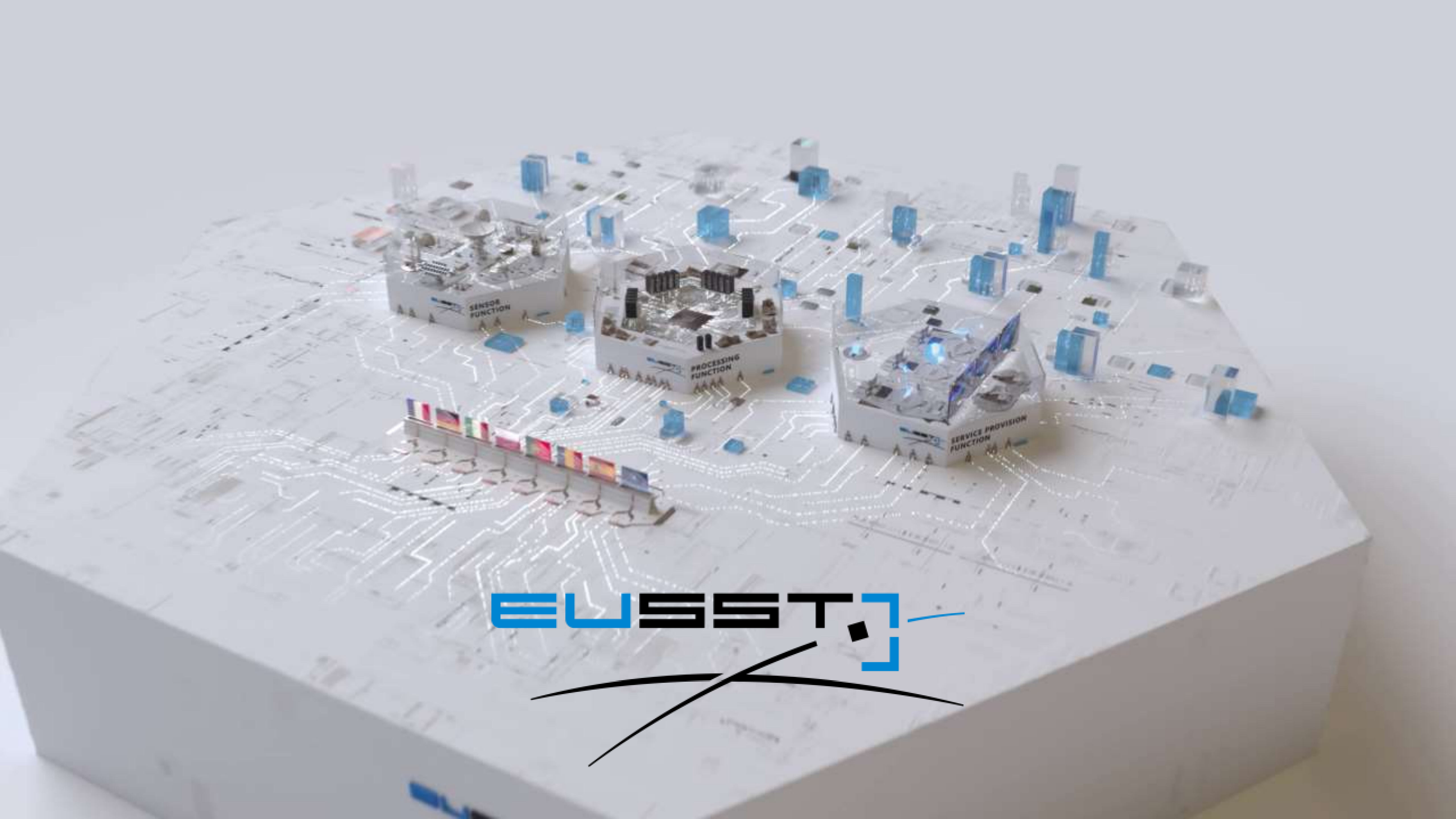
Source: NSR

Current and future trends

European and international policy environment:

- Space Traffic Coordination and Management: Pragmatic approaches for dealing with increased traffic in orbit
- Developments in Europe on the institutional and commercial side
- New EU Space Programme and other relevant EU initiatives (e.g. EDF, PESCO)

Regulation (EU) 2021/696


SENSOR FUNCTION
PROCESSING FUNCTION
SERVICE PROVISION FUNCTION
EUSST

EU SST Architecture studies

Dr Emmanuel Delande, SST Cooperation

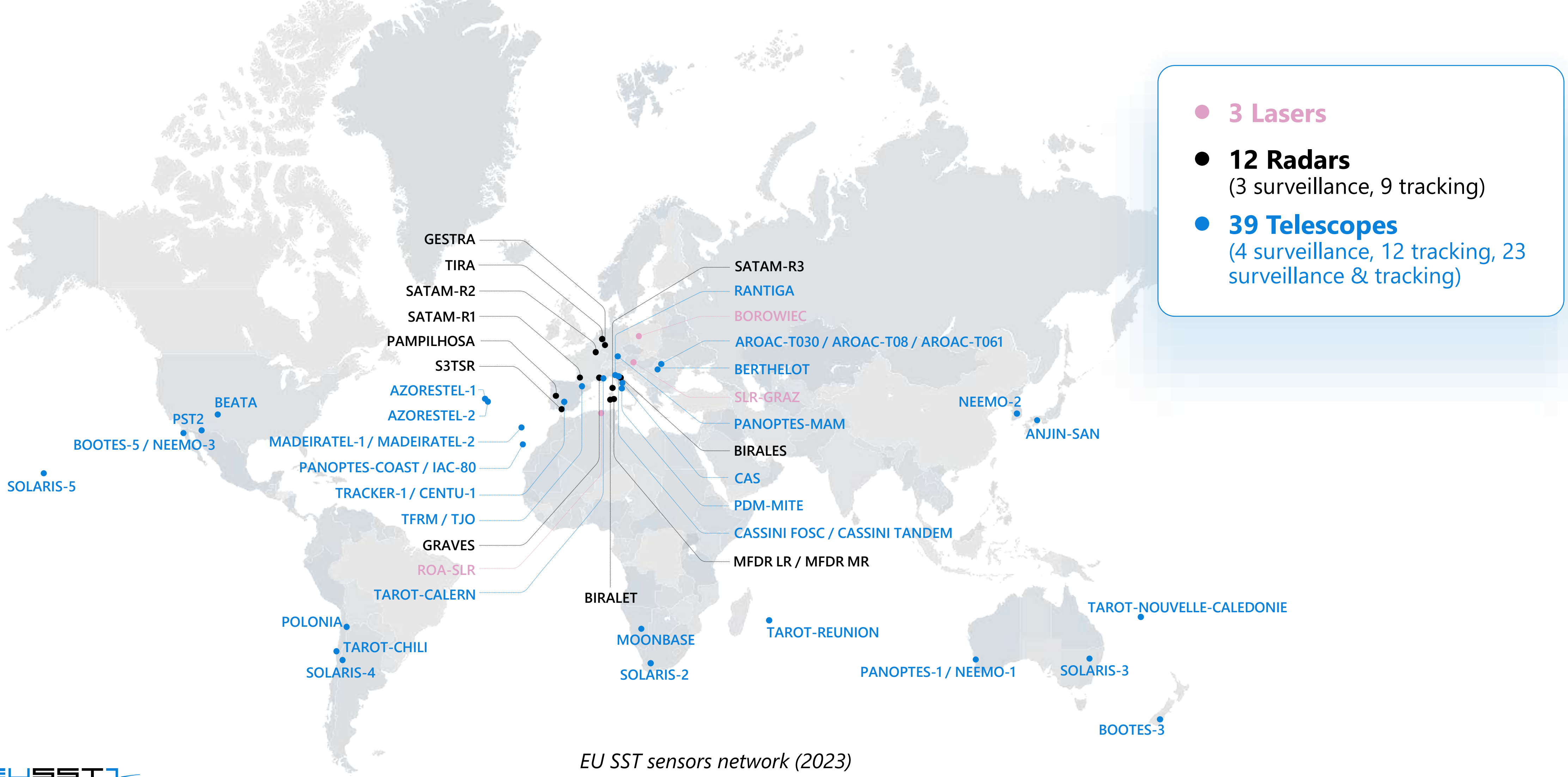
5 October 2021

First things first… why doing architecture studies?

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

- **Key features:**
  - *Flexibility and adaptability*: analysis framework accommodates for various scenarios, sensor networks, and performance points
  - *Traceability and reproducibility*: analyses are produced through a controlled and simulated environment
  - *Transparency and accountability*: simulation hypotheses and parameters are discussed with, justified to, and agreed upon by member states
  - *Robustness and validity*: analyses are crossed-checked through two independent test benches, AS4/Ssasim & BAS3E

Meet the 2023 EU SST network



EU SST sensors network (2023)

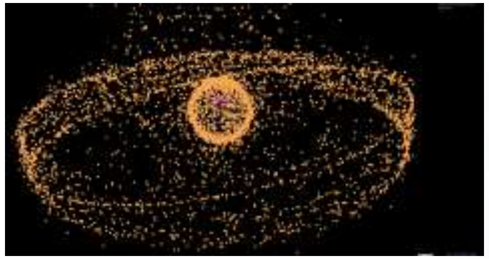
- **3 Lasers**
- **12 Radars** (3 surveillance, 9 tracking)
- **39 Telescopes** (4 surveillance, 12 tracking, 23 surveillance & tracking)

Today, what do we use architecture studies for?

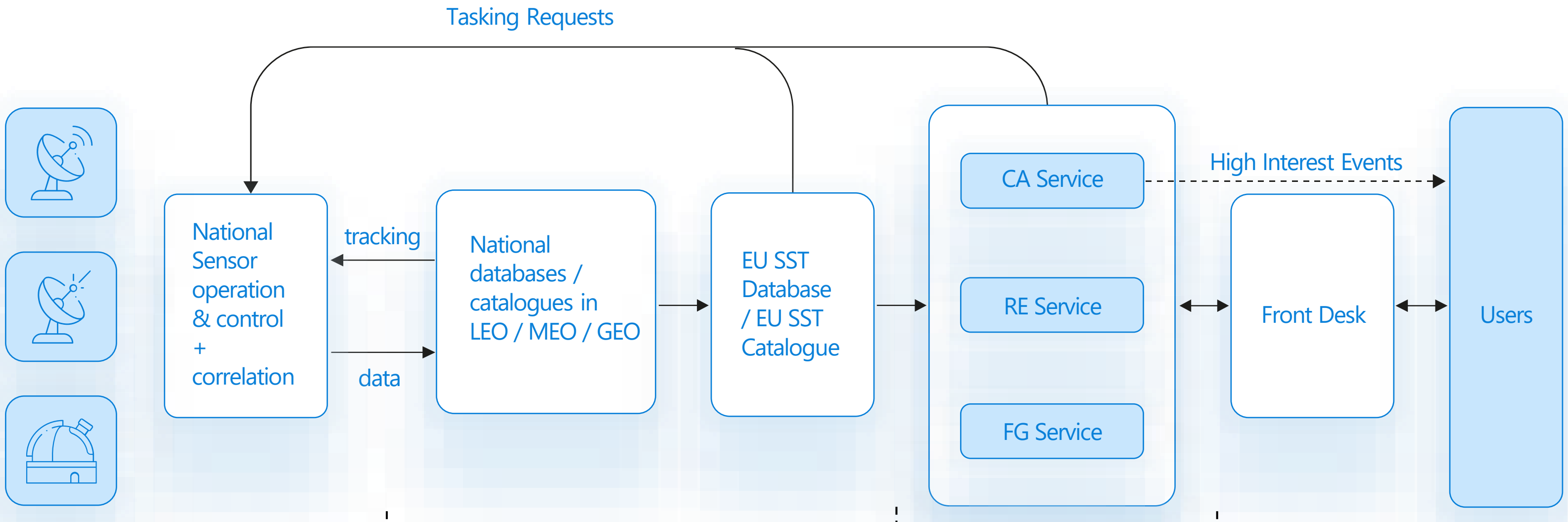
- **Bespoke scenarios,** to assess different features of a SST system:
  - *Coverage*: ability to observe a population of interest (e.g. LEO region) throughout time
  - *Cataloguing*: ability to maintain custody of the objects of interest, and to produce actionable information about them
  - *Service provision*: ability to detect, follow, and analyse events of interest
    - CA (Collision Avoidance): predict high-risk events, estimate epoch and probability, recommend manoeuvres
    - RE (Re-entry): predict re-entries, estimate epoch and entry point
    - FG (Fragmentation): identify parent object(s), track cloud debris
- **Flexibility is key**: *scope* of studies and simulations evolves with EU SST *needs and objectives*

Building an SST scenario: outline

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



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



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

Population modelling: challenges and features

- **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

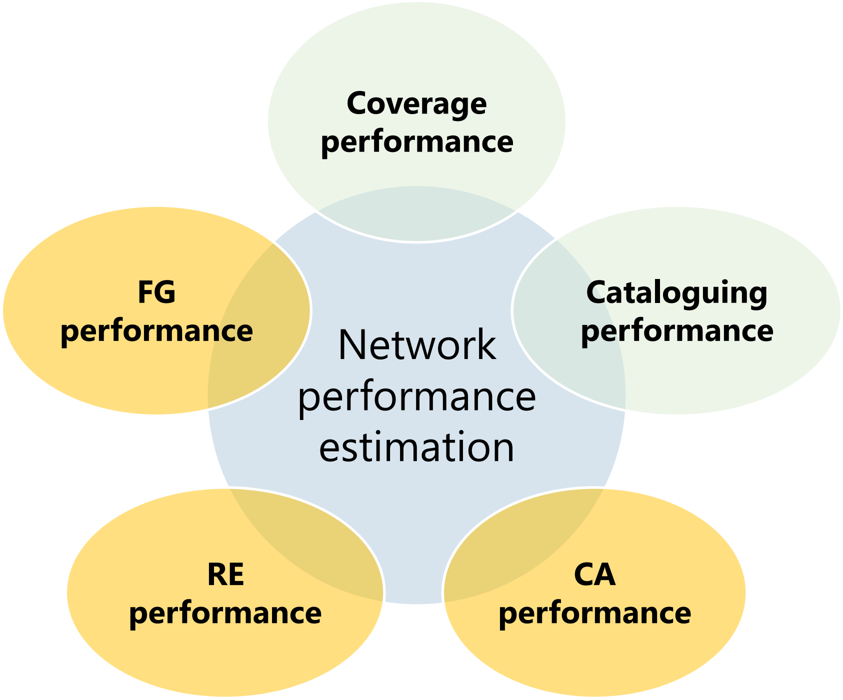
- **Orbital propagation** accounts for modelling mismatches in operational conditions:

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

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 (to appear)

The five pillars of performance evaluation

- **No single quantity** may assess a network "performance"
- Performance assessed through **five pillars**
- **Inter-dependent** features affecting overall performance
- Strong **focus on end-user**'s perspective
- **Flexibility is (yet again!) key**: performance evaluation shaped by EU SST needs



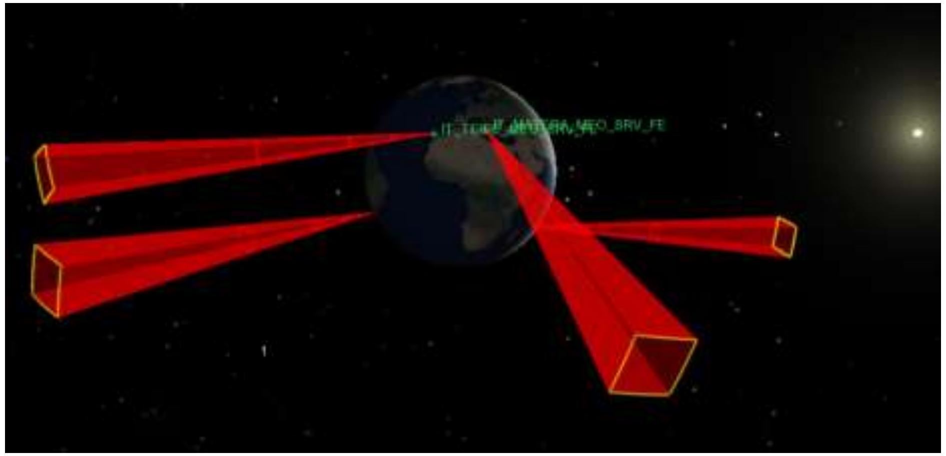
V. Morand *et al.* "Evaluating the performance of current and future EU Space Surveillance and Tracking system", *72nd International Astronautical Congress (IAC)*, 2021 (to appear)

Coverage performance

- Focus on **sensor layer**
  - Which objects are observable? From which sensors?
  - How often can they be observed?
  - How timely are the observations?

- **Performance evaluation**
  - *Compute* visibility, per object and per sensor
  - *Identify* observed and well-observed objects
  - *Build* sensor coverage statistics, identify redundancies

- Main **challenges**
  - *Model* detection capabilities
  - *Implement* surveillance strategies
  - *Integrate* tracking sensors



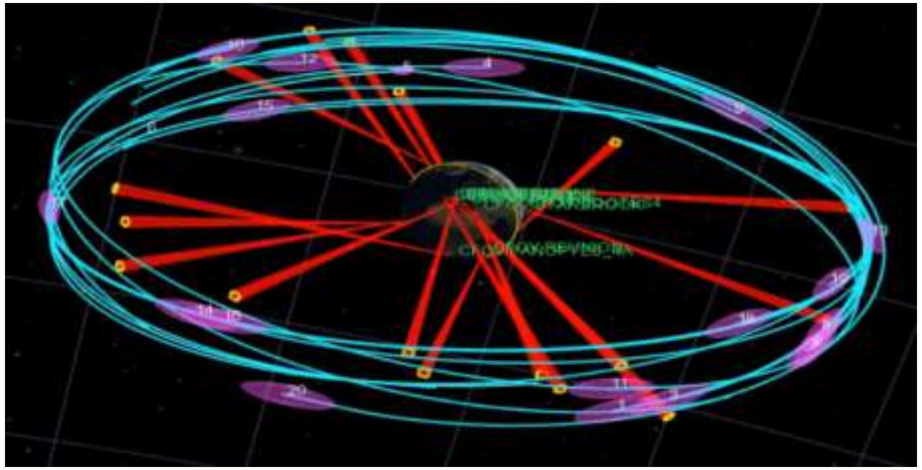
Surveillance strategy for an SST scenario (illustration with CNES VTS)

Cataloguing performance

- Focus on **data processing layer**
  - Do we lose objects in our catalogue?
  - How well do we keep track custody?
  - How actionable is our catalogue?

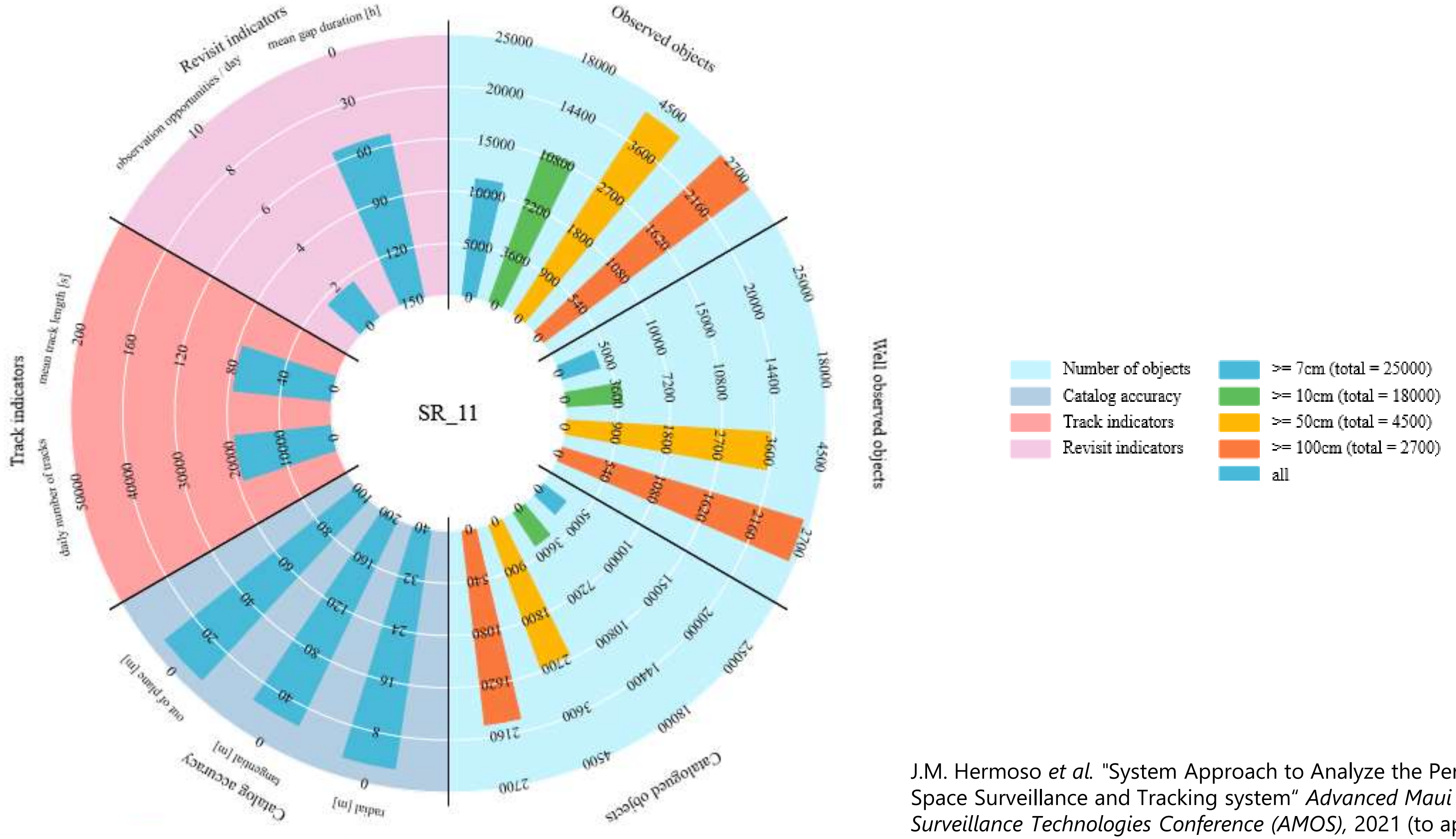
- **Performance evaluation**
  - *Check* predicted covariance beyond scenario horizon
  - *Determine* catalogued objects upon covariance value
  - *Compare* catalogue with reference population

- Main **challenges**
  - *Handle* data-to-object association
  - *Quantify* and *propagate* orbit uncertainty
  - *Define* suitable threshold for actionable covariance



Cataloguing in a SST scenario (illustration with CNES VTS)

Coverage/cataloguing performance: example output



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 (to appear)

CA service and performance evaluation

CA service

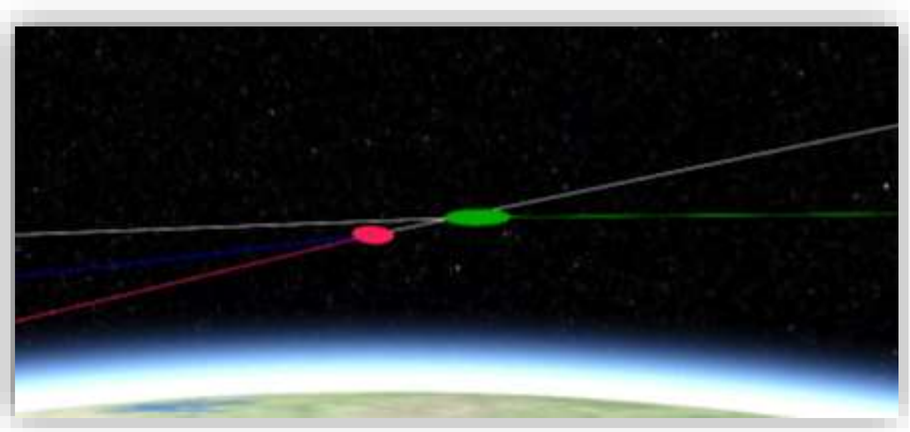
- Are we able to detect conjunction events?
- If so, can we observe the objects prior to the event, and learn about the conjunction?
- If so, how does it help us reducing risks for on-orbit satellites?

Performance evaluation

- *Check* predicted conjunctions against true ones
- *Compare* TCA, missed distance, collision probability

Main **challenges**

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

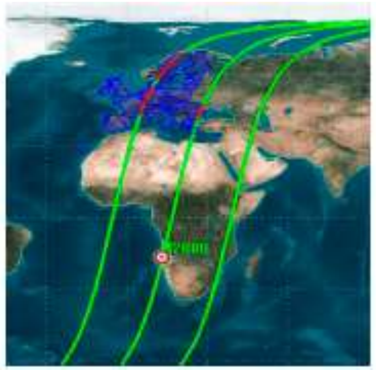


Collision Avoidance representation

RE service and performance evaluation

RE service

- Are we able to detect re-entry events?
- If so, can we observe the object prior to the event, and learn about its re-entry?
- If so, how does it help us reducing risks for populations?



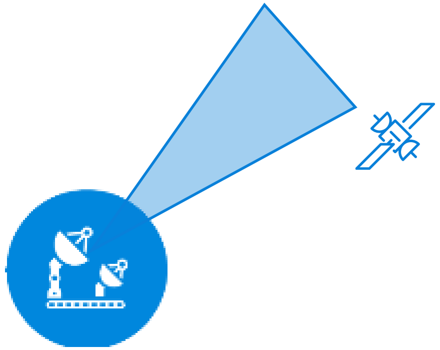
Re-entry Analysis representation

Performance evaluation

- *Check* predicted re-entries against true ones
- *Compare* re-entry epoch & atmospheric entry point

Main **challenges**

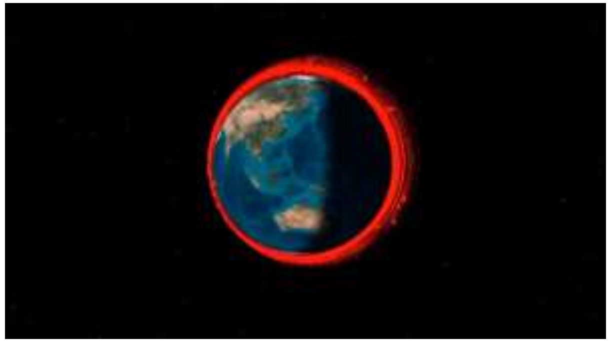
- *Build* a reference population of re-entering objects
- *Mitigate* model uncertainties in shaping true re-entry epochs
- *Integrate* tracking sensors, *implement* “no-show” events



FG service and performance evaluation

FG service

- Are we able to detect fragmentation events?
- If so, can we identify the origin object(s)? Observe the resulting cloud?
- If so, how many fragments can we detect and catalogue?



Fragmentation Analysis representation

Performance evaluation

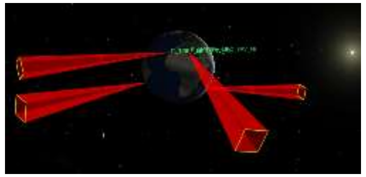
- (Ongoing activity, to be determined)

Main **challenges**

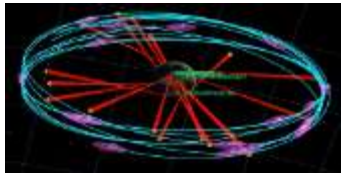
- *Model* measurement process when observing a cloud
- *Handle* data-to-object observation in dense environments
- *Perform* Initial Orbit Determination (IOD) upon debris detection

Architecture studies in a nutshell

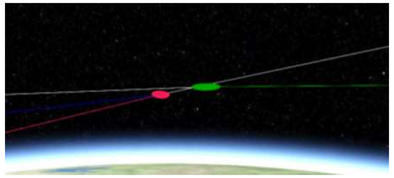
- **Comprehensive simulation framework**, covering the full signal processing chain in a SST system
- **Implementation of bespoke scenarios**, tailored to specific analyses of a SST system
- **Multi-layered performance evaluation**, reflecting five features of SST operational needs



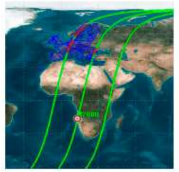
Coverage



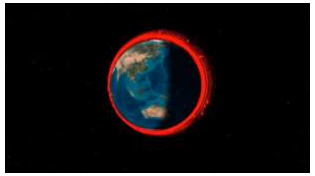
Cataloguing



Collision Avoidance



Re-entry Analysis

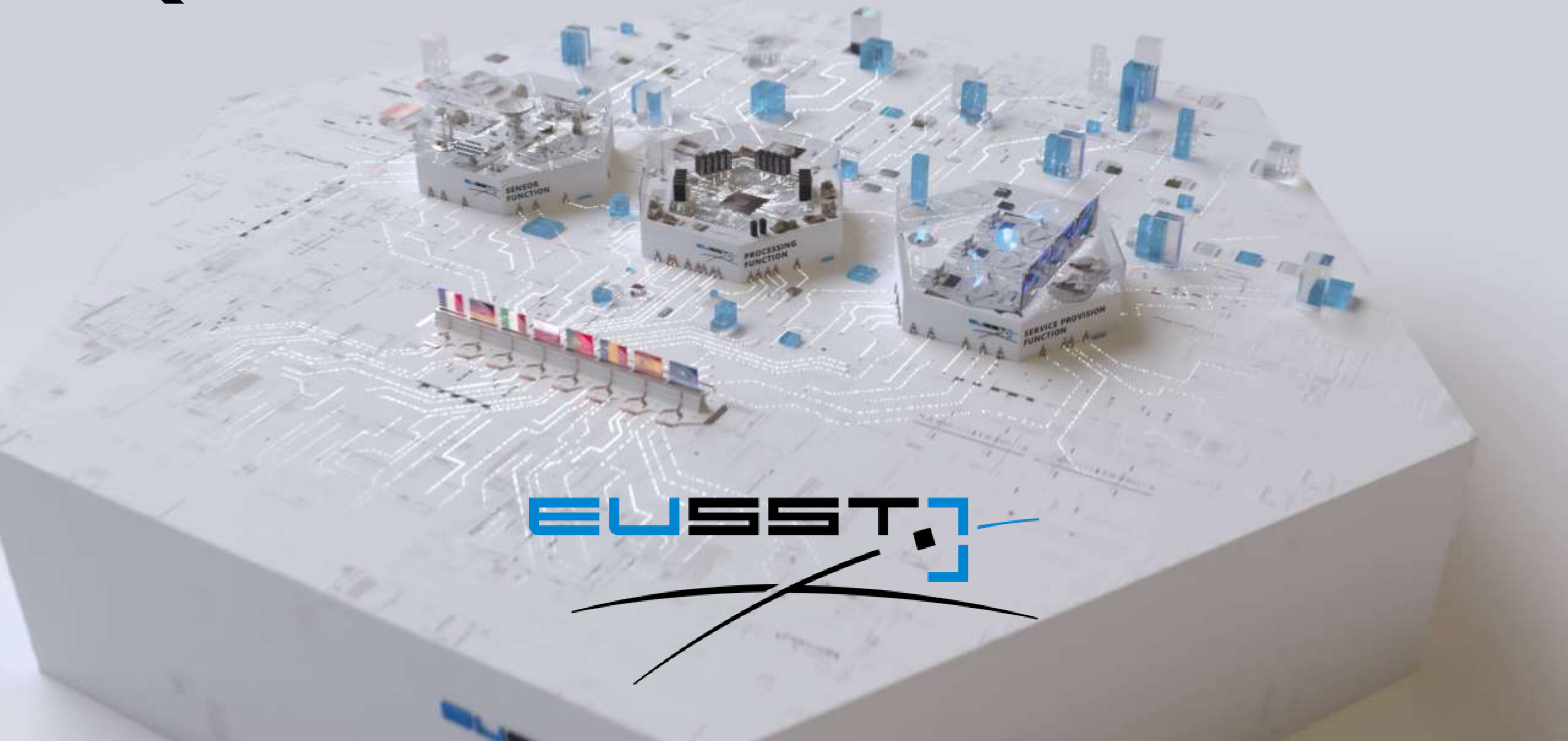


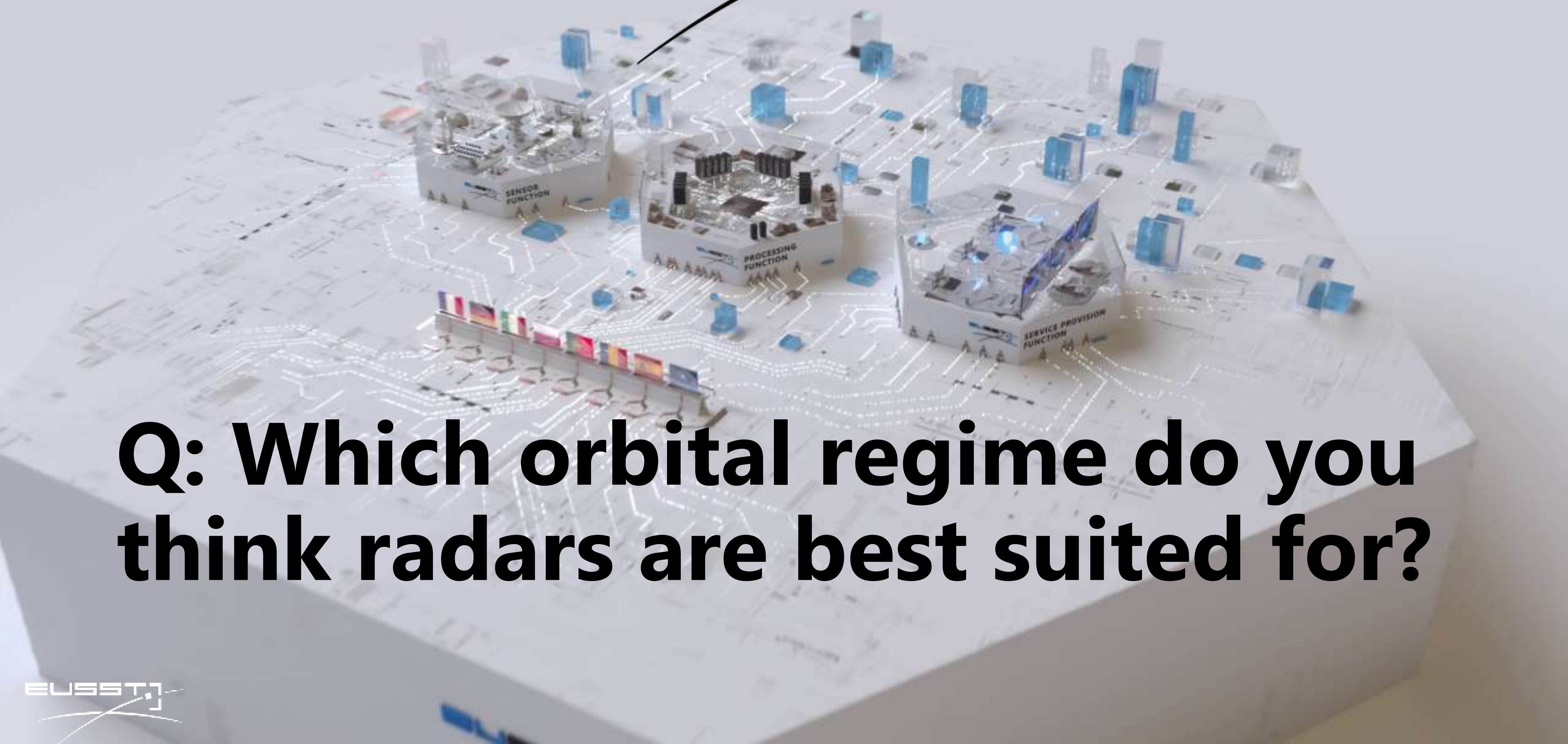
Fragmentation Analysis

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

a4 Ssasim BAS3E

Q&A session


SENSOR FUNCTION
PROCESSING FUNCTION
SERVICE PROVISION FUNCTION



Q: Which orbital regime do you think radars are best suited for?

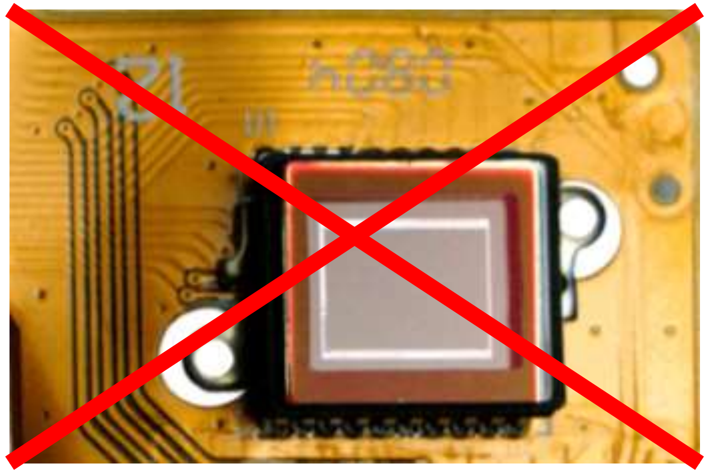
EU SST Capability development: sensor upgrades in the context of EU SST

Konrad Bojar, SST Cooperation
5 October 2021

Objectives and outcomes

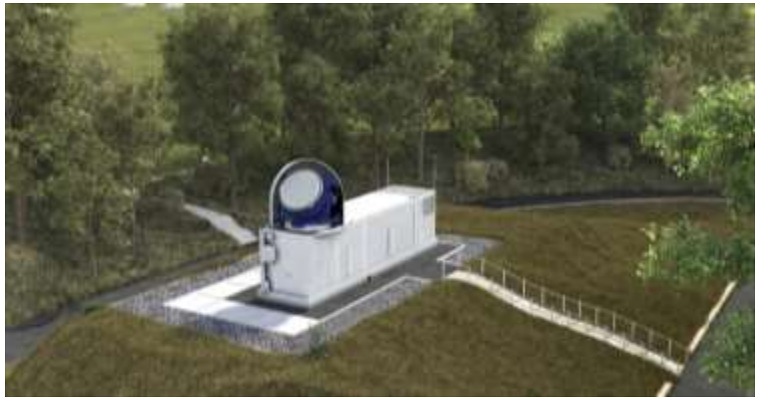
- The **EU SST constantly evolves** on several layers
  - End-user interface
  - Services
  - Data coverage and quality
- Focus of this presentation → sensors
- **Better sensors = better data**
  - New sensors give better coverage
  - Upgraded sensors give better quality
- **Upgrades are optimised globally**
  - Optimisation is network-wide, not national
  - Value for money and value for time are important factors
  - Risk management is a key task

What is a sensor in EU SST?



Context

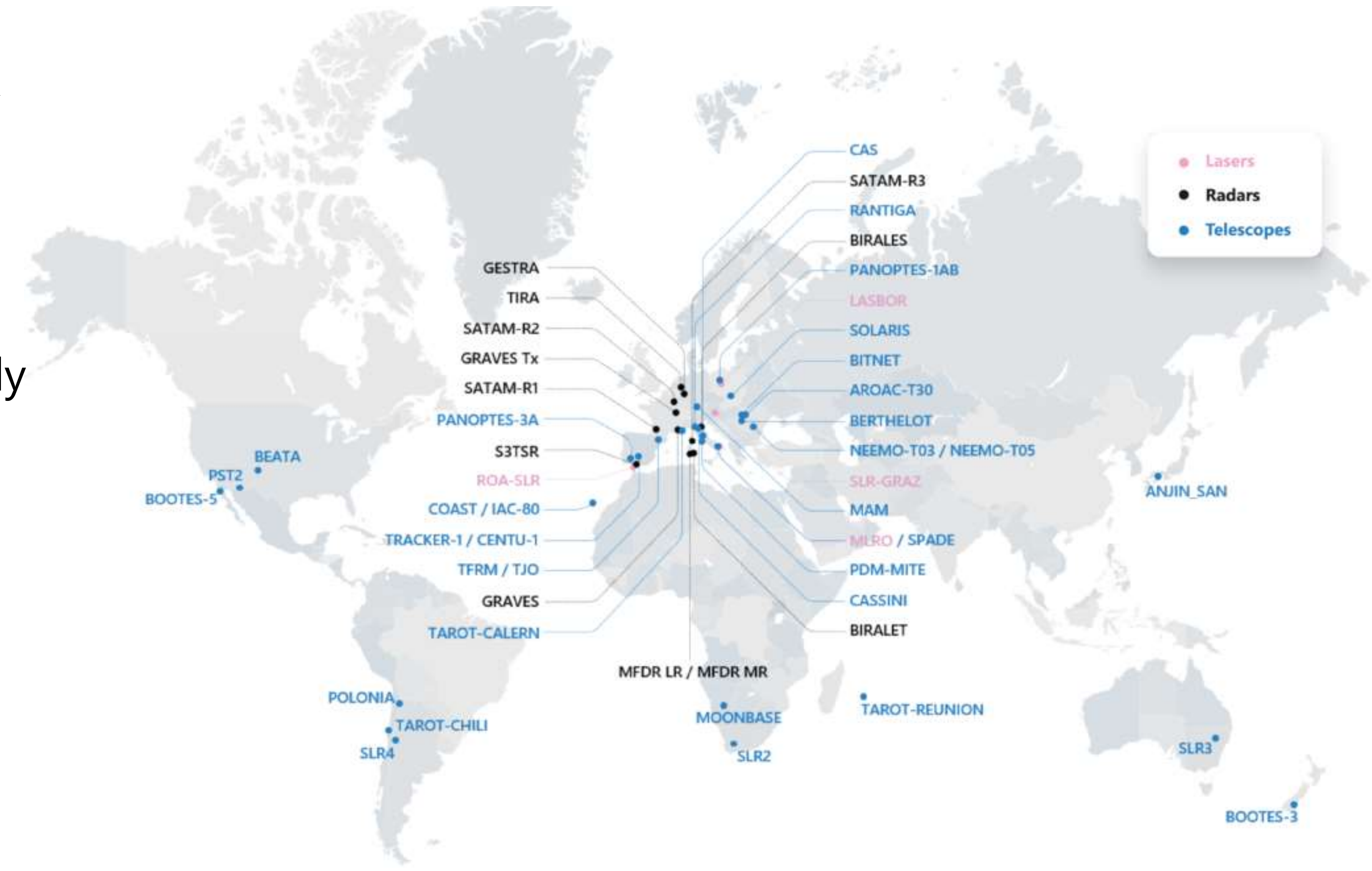
- EU SST network upgrade is a challenge for the industry and EU Member States
- There are numerous aspects of upgrades:
  - antennas (*electromagnetic sensors*)
  - electronics (eg. *imaging sensors*)
  - buildings
  - optics
  - mechanical mounts
  - domes
  - software
  - processes
- Industry leaders are with us today to show examples of large-scale upgrades
  - Fraunhofer FHR for (DE) for GESTRA EU SST radar
  - Indra (ES) for S3TSR radar



GESTRA EU SST and S3TSR radars

Sensor upgrades in the context of EU SST

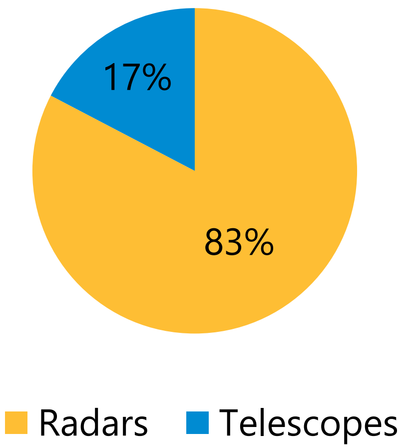
- SST Consortium is working on upgrading its whole sensor network
- Primary objective: Improve the performance of the EU SST system through capability expansion and extension of sensor network
- This presentation will treat separately
  - Radars
  - Telescopes

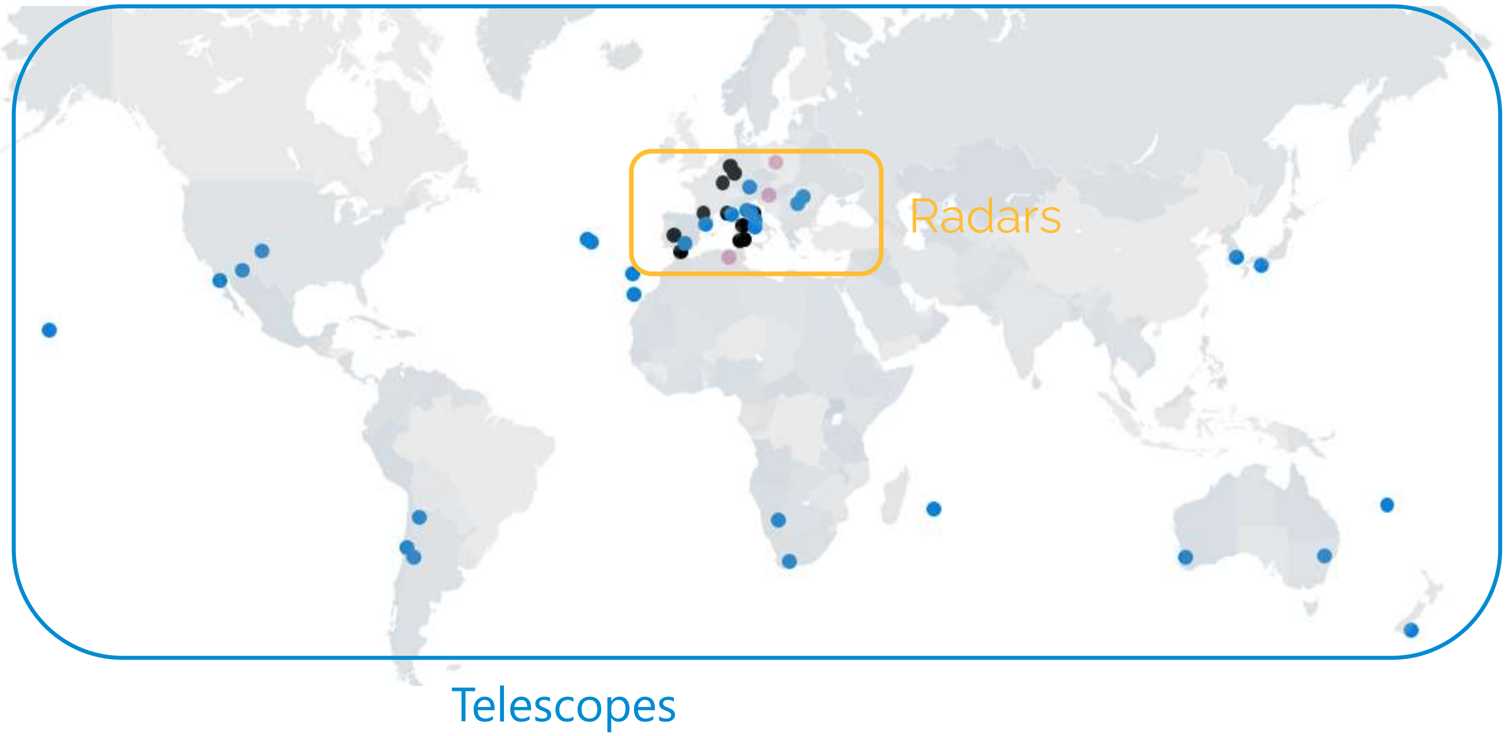


EU SST sensors network (2021)

Sensor upgrades in the context of EU SST

- Upgrades of **radars** differ greatly from upgrades of **telescopes** in
  - **Budget**
  - **Sensor locations**





EU SST radar upgrades

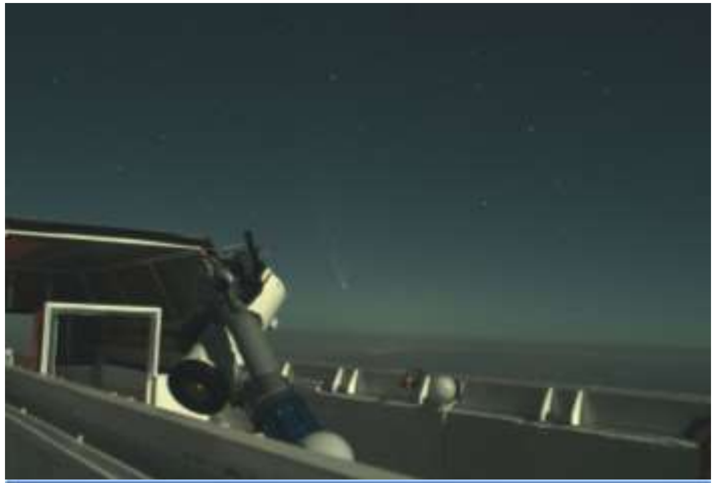
- Radars being upgraded

Radars	Performance improvement
GESTRA	Sensitivity ↑ *
S3TSR	Sensitivity ↑
GRAVES	Sensitivity ↑
BIRALES	Sensitivity ↑
MFDR	Sensitivity ↑ **
Pampilhosa	Sensitivity ↑

* also bi-static measurement added
** also field of view extended

EU SST telescope upgrades

- Telescopes being upgraded
  - Tarot network (4 units, FR)
    - New unit in New Caledonia
    - Autonomic operation extension
  - Polish network (6 units, PL)
    - Homogenous upgrade in six locations
      - Asia, Oceania, Americas, Pacific, South Africa
    - Very Wide Field of View extensions
  - NEEMO network (3 units, RO)
    - Relocation from Romania to Australia
    - New units in two locations (Mexico and South Korea)
  - Cassini (2 units, IT)
  - Centu and TJO (ES)
  - Azores (PT)



Challenges and future steps

- Challenges
  - We are facing supply chain disruptions
  - Global lack of semiconductors
  - Raw materials price surge
  - Travel restrictions disrupt overseas deployments
- Future steps
  - Follow architecture study guidelines
  - Follow R&D activities outcomes
  - Follow upcoming legislation
  - Some steps already visible ahead:
    - Telescope network extension outside Europe
    - Radar network extension outside Europe

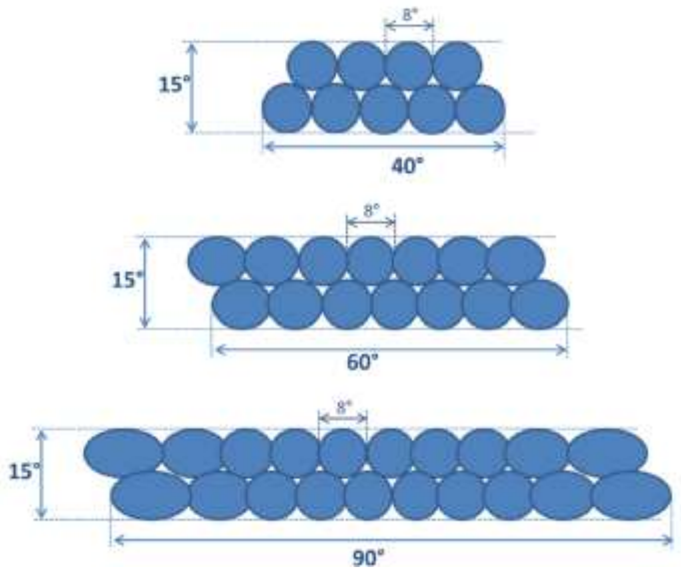
GESTRA EU SST

Christoph Reising (Fraunhofer FHR), Head of team signal processing GESTRA EU SST
5 October 2021

GESTRA EU SST

GESTRA and GESTRA EU SST System

- GESTRA (German Experimental Space Surveillance and Tracking Radar)
  - quasi-monostatic radar system located in Koblenz, Germany
  - can perform tracking and surveillance modes
  - surveillance areas can be placed in different positions, different search modes included



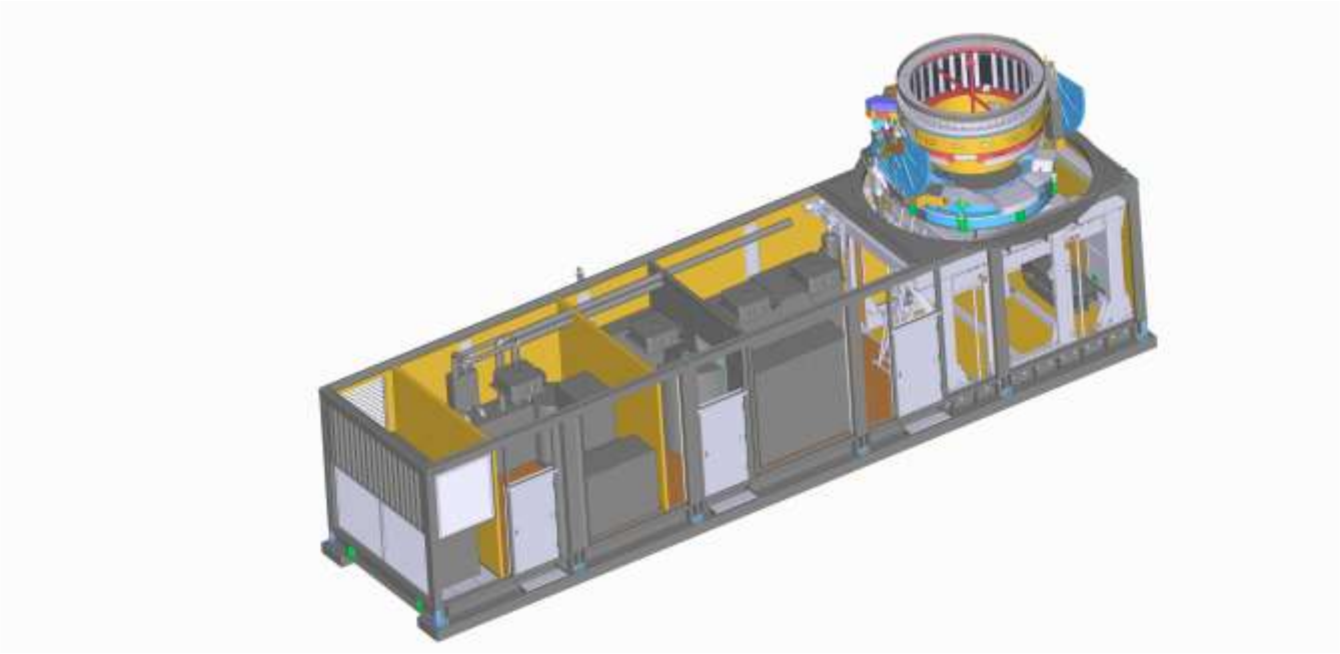
- Upgrade GESTRA EU SST:
  - bistatic operation
  - performance gain in SNR and parameter estimation
  - Fraunhofer FHR is building up the system GESTRA EU SST under contract to DLR German Space Agency

DLR Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

Fraunhofer
FHR

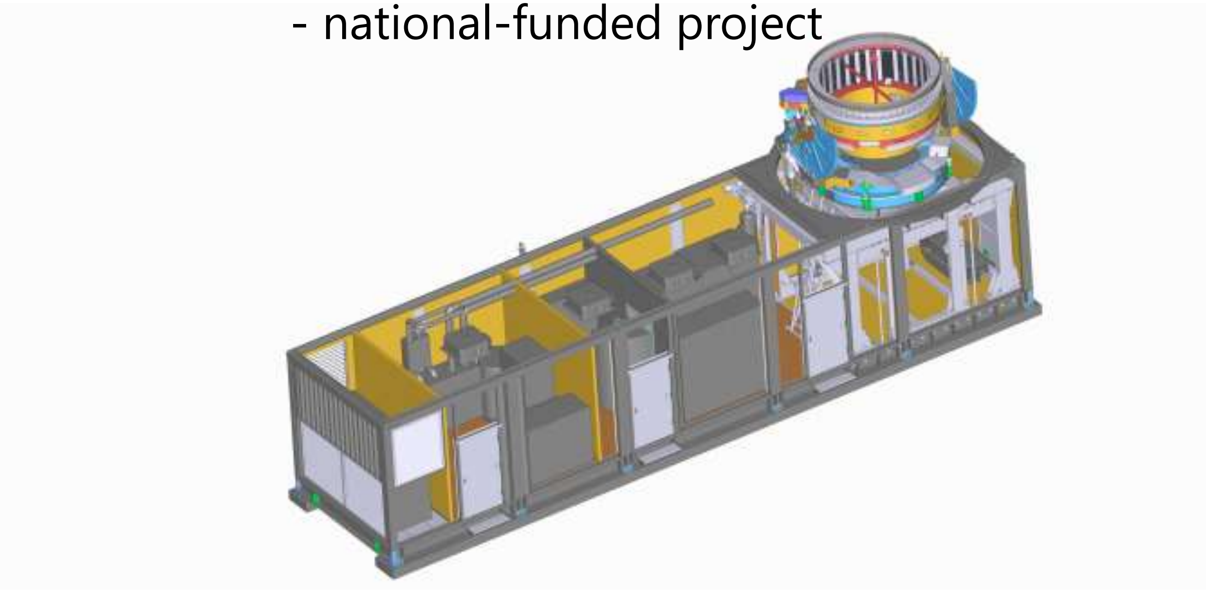
GESTRA EU SST and *GESTRA Network*

- “GESTRA EU SST“ and “GESTRA Network“ are two closely related projects at Fraunhofer FHR
  - “GESTRA EU SST“ focusses on building up an additional GESTRA Receiver (Rx)
    - EU-funded project



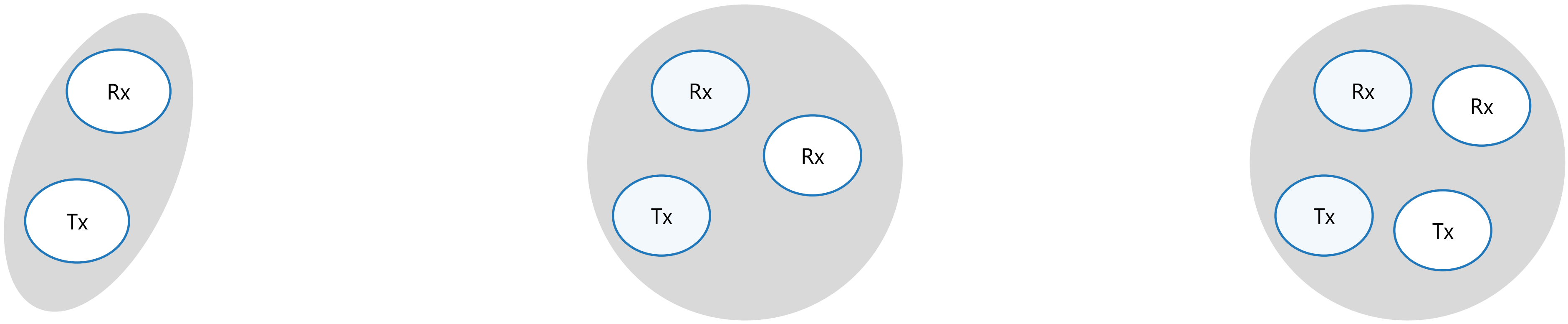
GESTRA EU SST and GESTRA Network

- "GESTRA EU SST" and "GESTRA Network" are two closely related projects at Fraunhofer FHR
  - "GESTRA EU SST" focusses on building up an additional GESTRA Receiver (Rx)
    - EU-funded project
  - "GESTRA Network" focusses on the networking and data fusion of "GESTRA" and "GESTRA EU SST"
    - national-funded project



GESTRA EU SST performance gain

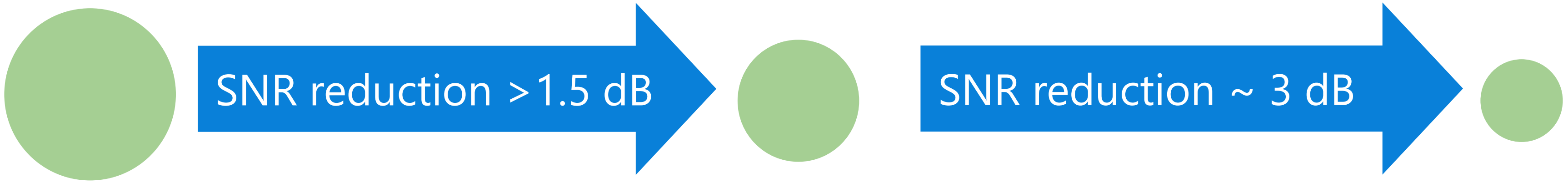
- Performance of a monostatic GESTRA system (Tx/Rx) compared to two different scenarios of possible GESTRA sensor networks
  - Performance improvement in terms of **detection capability**:



GESTRA (Tx/Rx)

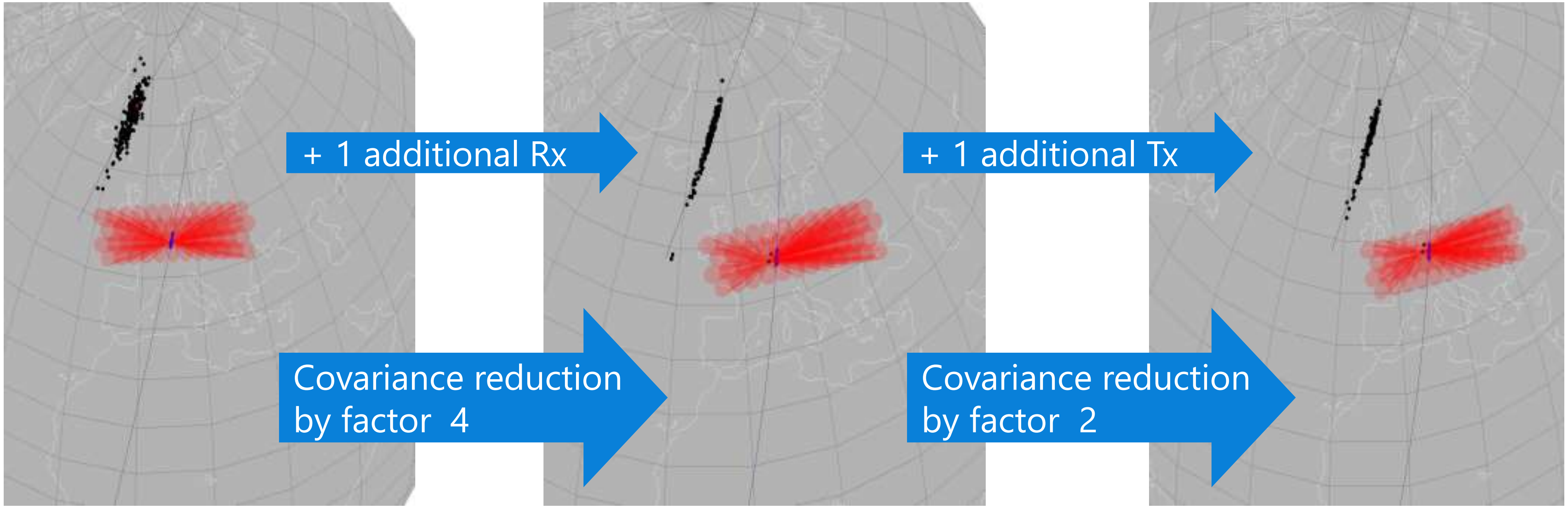
GESTRA (Tx/Rx) + **GESTRA EU SST (Rx)**

GESTRA (Tx/Rx) + **GESTRA EU SST (Rx)**
+ another transmitter



GESTRA EU SST performance gain

- Performance of a monostatic GESTRA system (Tx/Rx) compared to two different scenarios of possible GESTRA sensor networks
  - Performance improvement in terms of **uncertainty reduction**:



GESTRA (Tx/Rx)

GESTRA (Tx/Rx) + **GESTRA EU SST (Rx)**

GESTRA (Tx/Rx) + **GESTRA EU SST (Rx)**
+ another transmitter

GESTRA EU SST

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S3TSR

Emilio Viedma (INDRA), Space Business Development Manager
5 October 2021

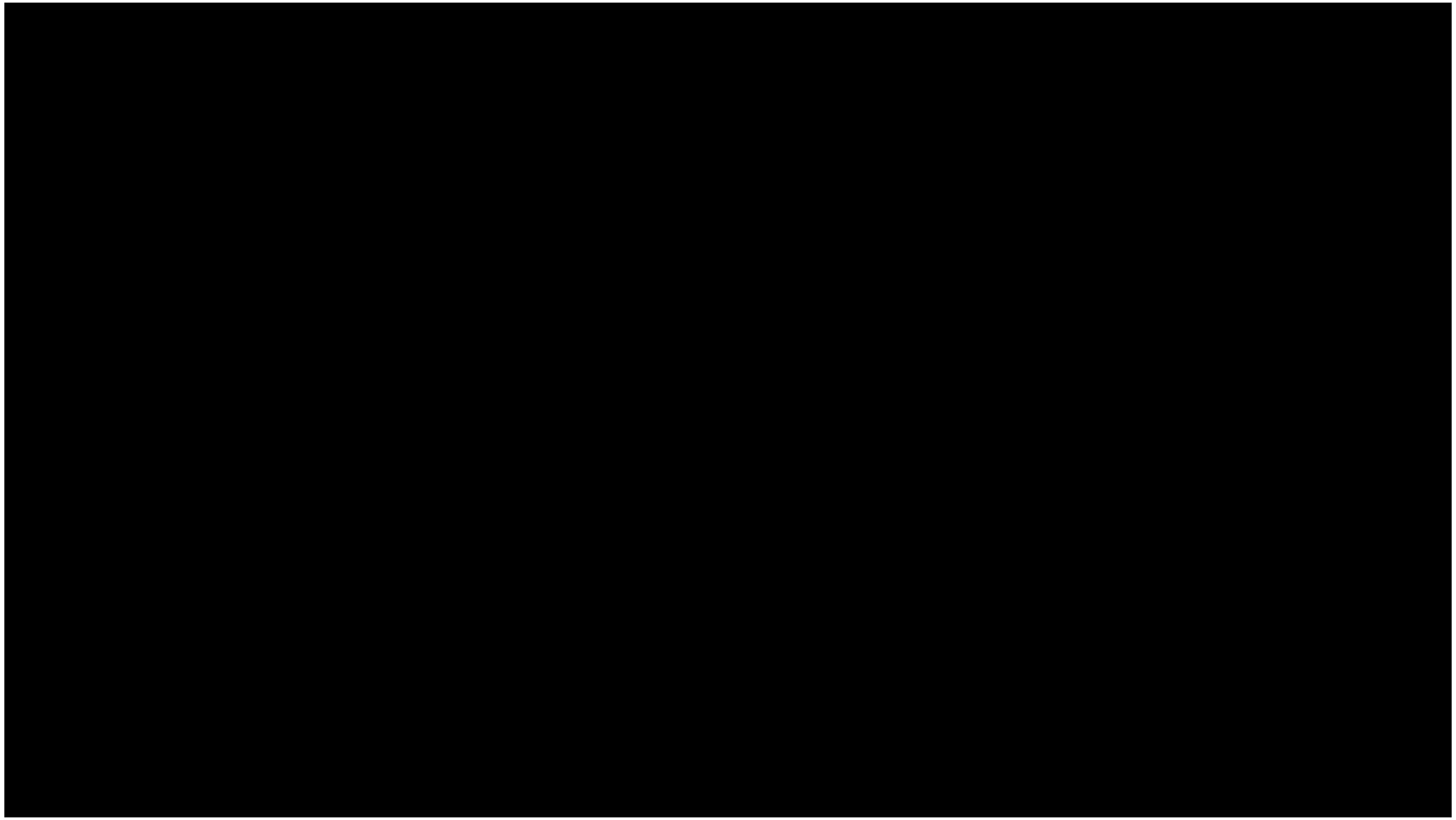
The space surveillance radar S3TSR

Close monostatic configuration

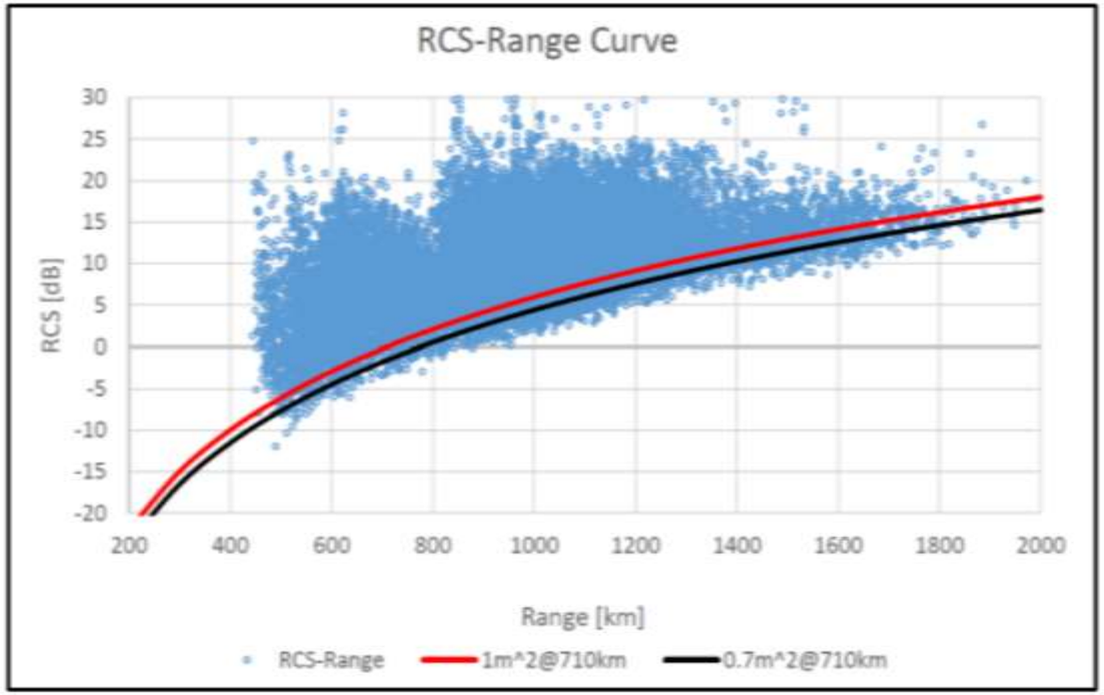
- Transmitter and Receiver arrays are not at the same location
- Distance between Tx and Rx facilities is small compared to the distance to the target
- Tx and Rx antennas are southward oriented, with the antenna plane forming 30º with the horizontal plane (boresight at elevation 60º)

S3TSR is deployed at Moron Air Base (Seville)

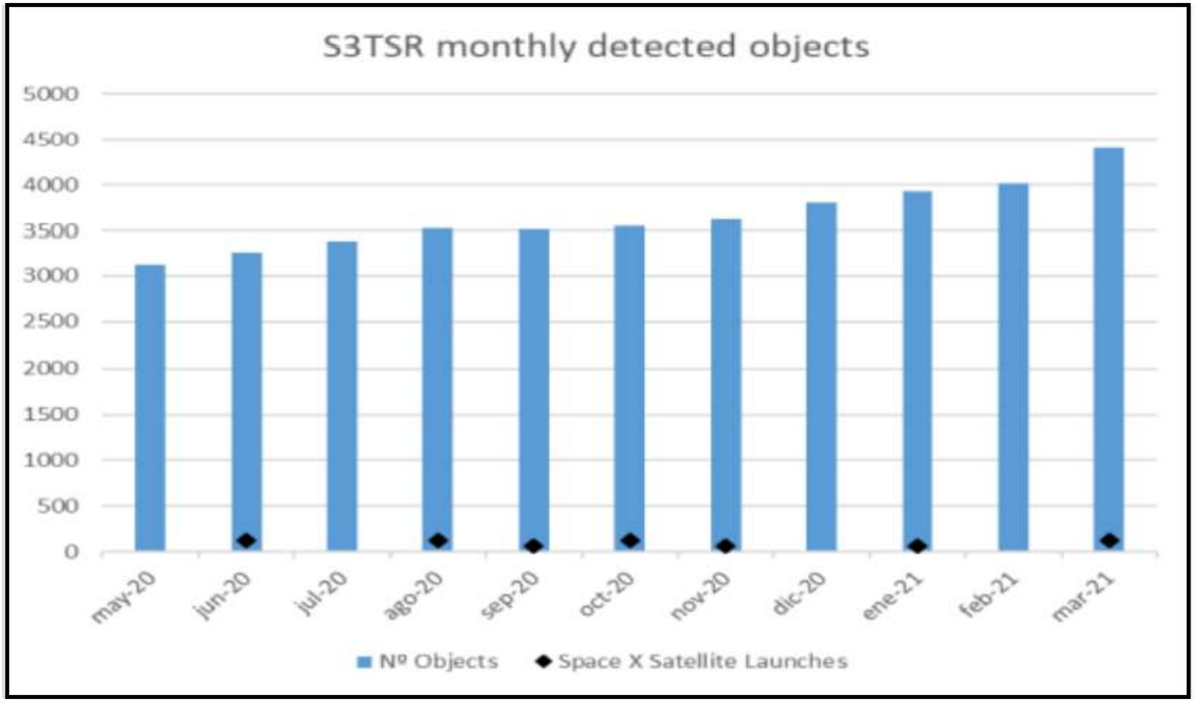
The space surveillance radar S3TSR



High performance of the initial version of S3TSR

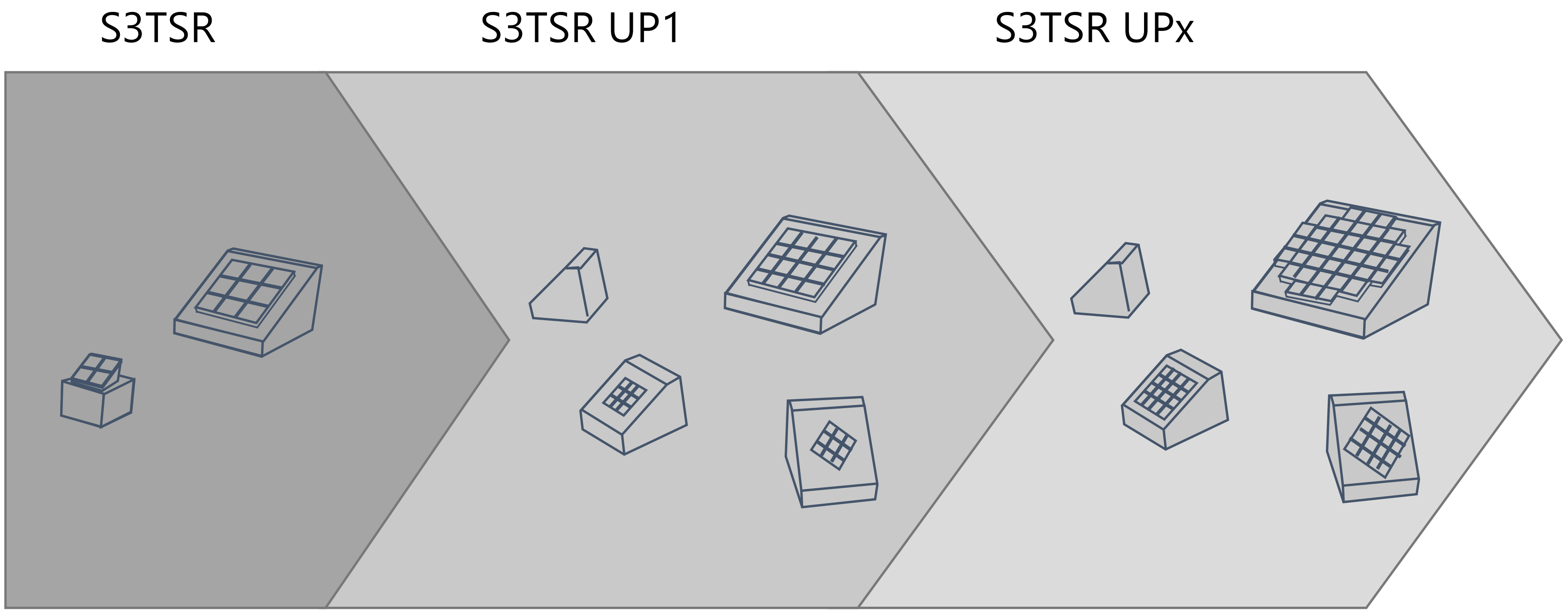


In red, the design RCS-Range curve and in black, the curve derived from the RCS analysis



Monthly evolution of the S3TSR different objects detected

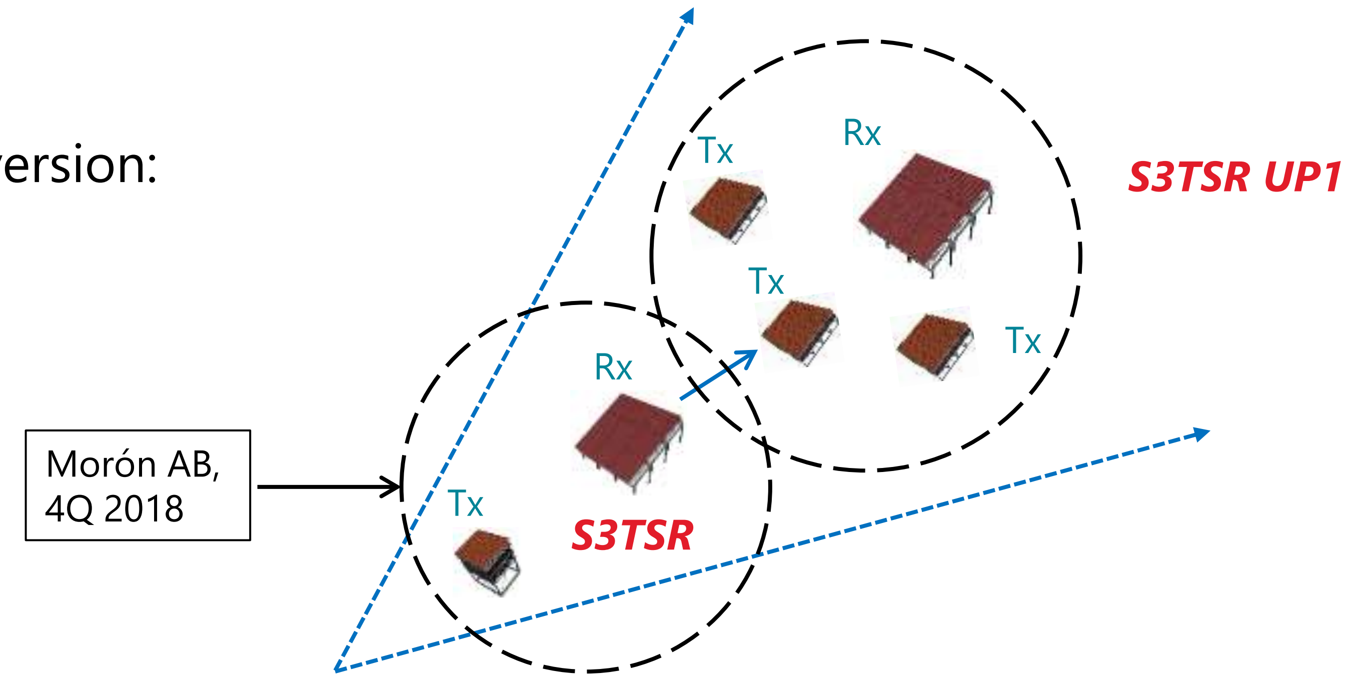
S3TSR evolution



- First operational version of the radar (1 Tx, 1 Rx) is operational since 2018
- Next version will include a new Tx, 4 times larger than the current one
- This version will be ready for being subsequently escalated up to 3 Tx, also enlarging progressively the power of each Tx

S3TSR UP1 performance

- Performance enhancement of next version:
  - Objects detected: x4
  - Detection capability: x18



S3TSR

Indra Point of Contact:
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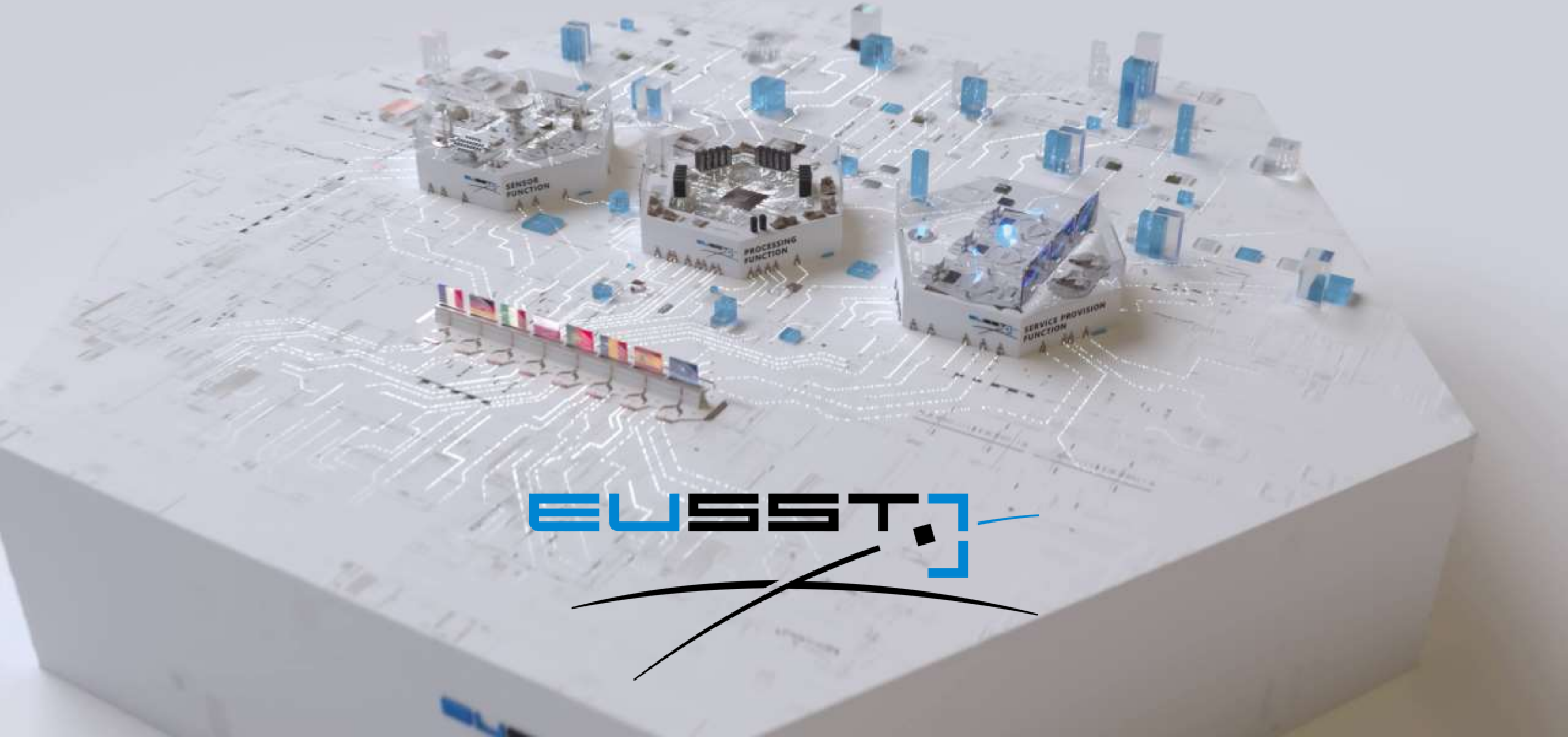
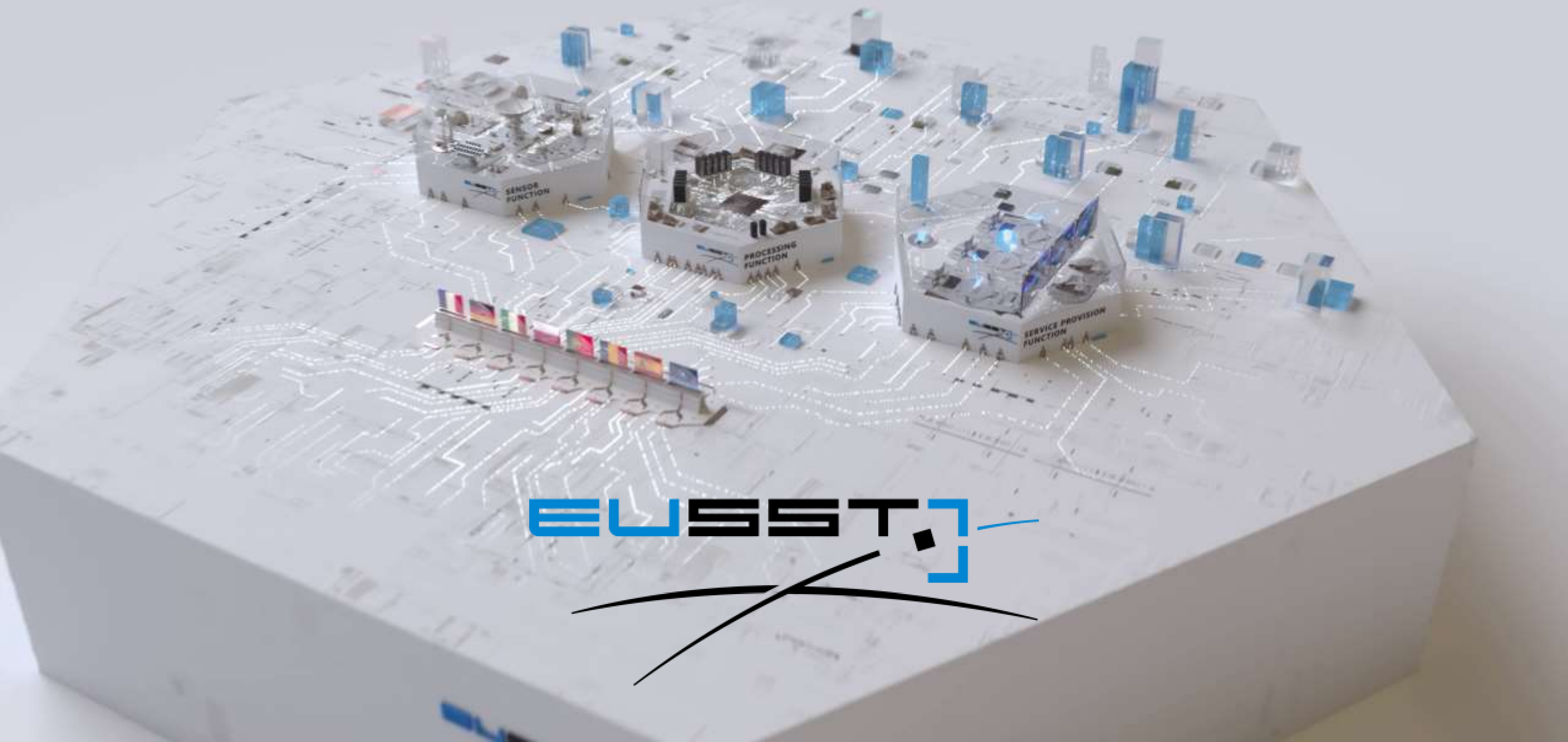
ejviedma@indra.es

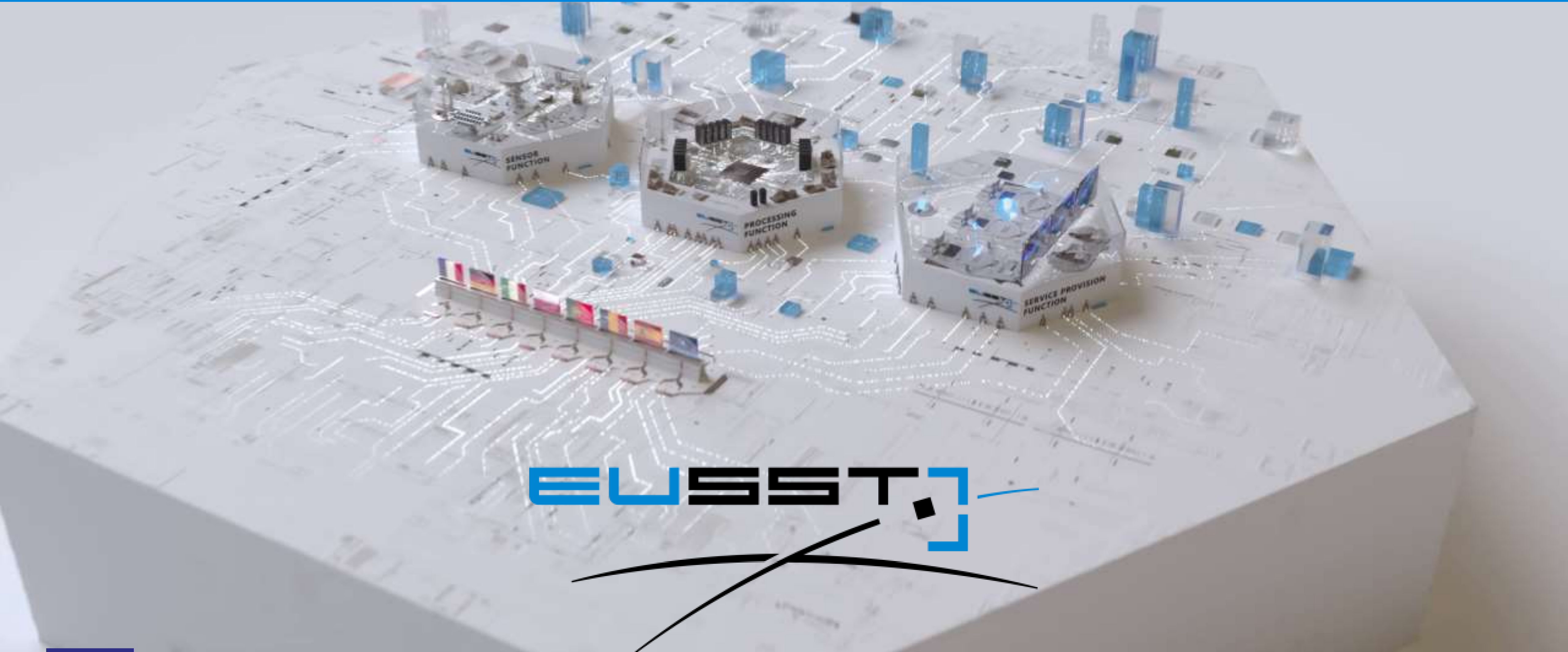
Q&A session


SENSOR FUNCTION
PROCESSING FUNCTION
SERVICE PROVISION FUNCTION

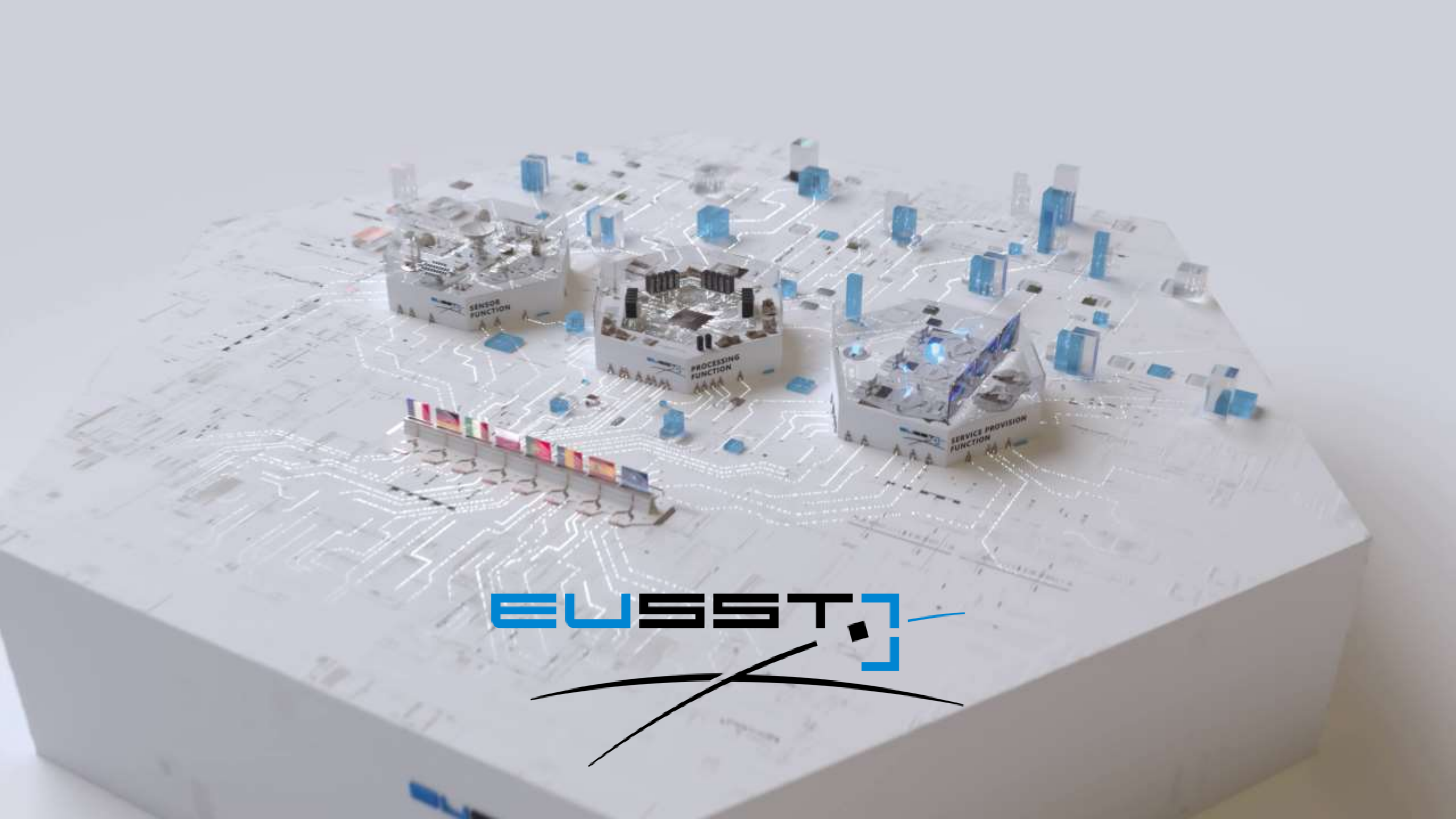
Break


SENSOR FUNCTION
PROCESSING FUNCTION
SERVICE PROVISION FUNCTION
EUSST

We’ll be back soon!



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 952852, No 785257, No 760459, 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. This message 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.


SENSOR FUNCTION
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SERVICE PROVISION FUNCTION
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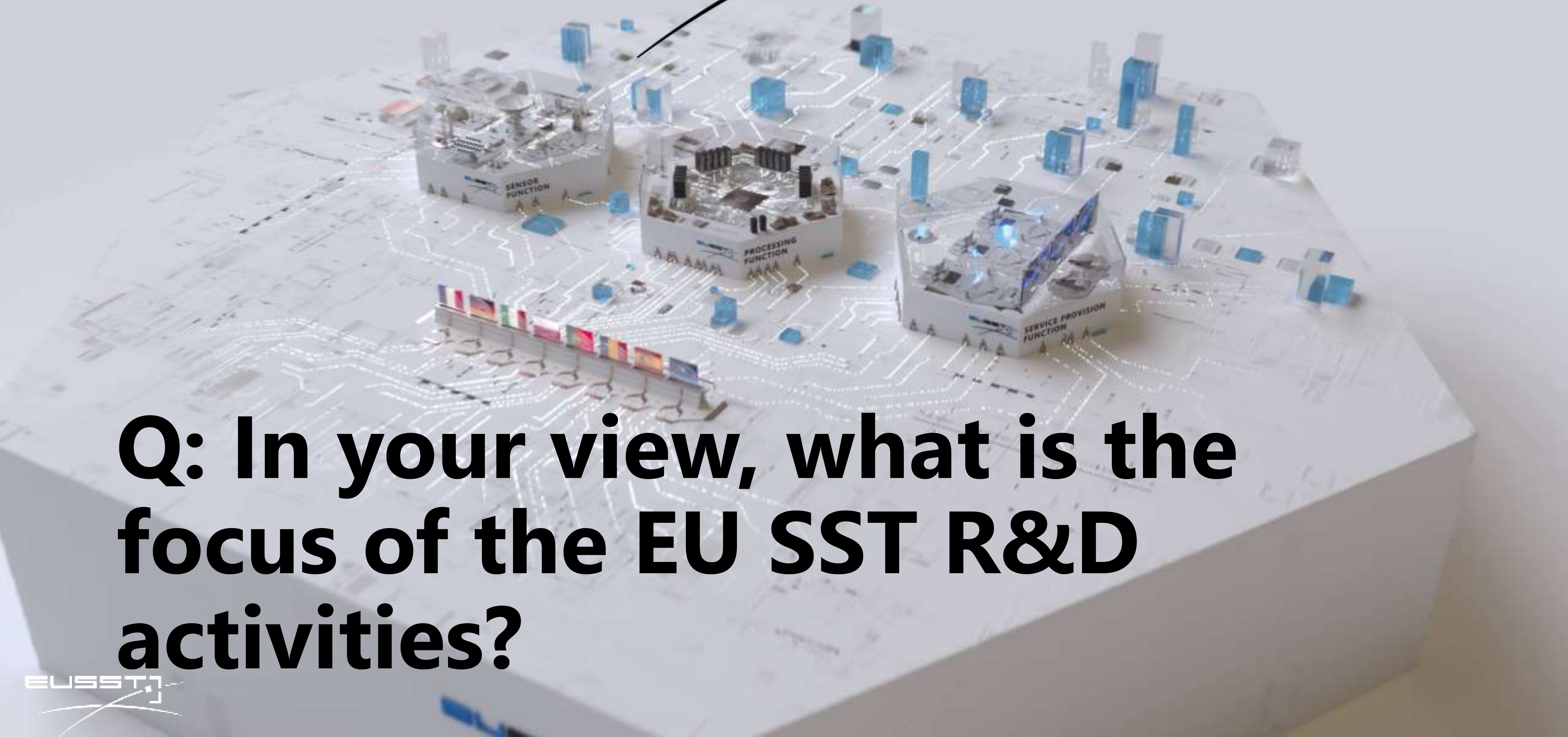
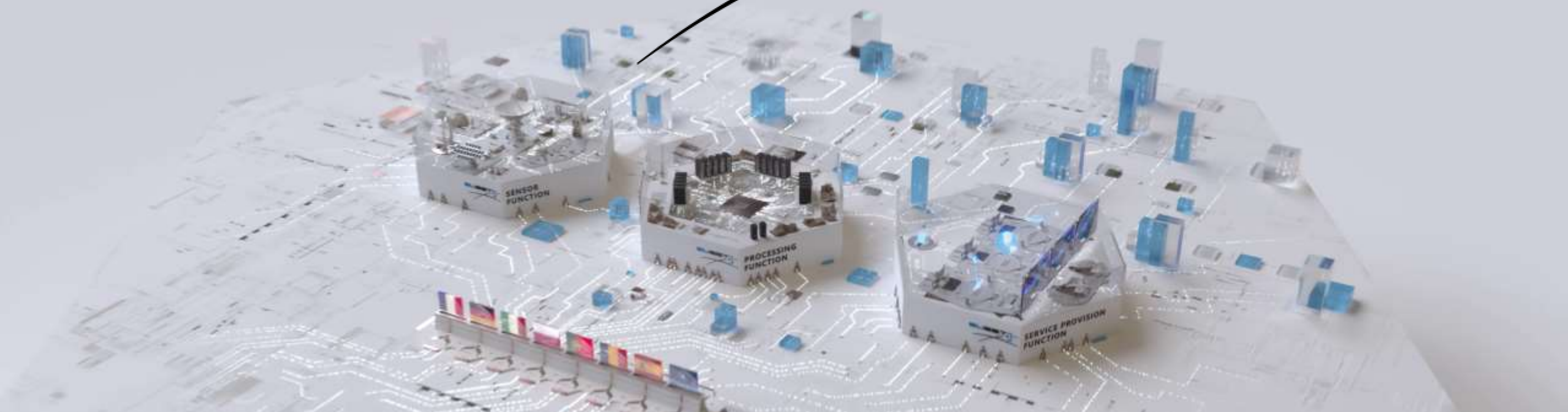


Q: In your view, what is the focus of the EU SST R&D activities?



Q: In your opinion, what is the most challenging aspect for SST data processing?

EU SST R&D activities

Vincent Morand, SST Cooperation
5 October 2021

R&D plan

- The SST Cooperation **Research and Development (R&D) plan** consists of a set of R&D activities covering all the system's layers to:
  - Facilitate a sustained **long-term evolution and enhancement of EU SST**
  - **Anticipate the needs and prepare for the future**

- For the implementation of the EU SST R&D plan, the Consortium **strongly involves industry, academia and start-ups**, with some 80% of the investments allocated through subcontracts

- The outputs of the R&D activities are evaluated through **architecture studies and system design activities**

- This process allows EU SST to assess and select the activities presenting **best value for money**

Global objectives

- Improve EU SST sensors' capability to achieve **high autonomy** in the observation and cataloguing of objects **in MEO and GEO**

- Reach an **appropriate autonomy level** to observe and catalogue objects **in LEO** which could have the biggest **impact on the space environment**

- Develop **new sensor technology** to better **characterise the orbital environment** and **new concepts of operations** (such as highly manoeuvrable objects or in-orbit servicing)

- Evolve **data processing capabilities** allowing EU SST to provide **top-quality services** (CA, RE, FG) to its users

2023

2028

- Improve EU SST sensors' capability to **increase autonomy** mainly in the observation and cataloguing of objects **in LEO**

- Develop and demonstrate **innovative Space Surveillance and Tracking sensors** (such as for space-based space surveillance) to enhance the safety and security of space operations

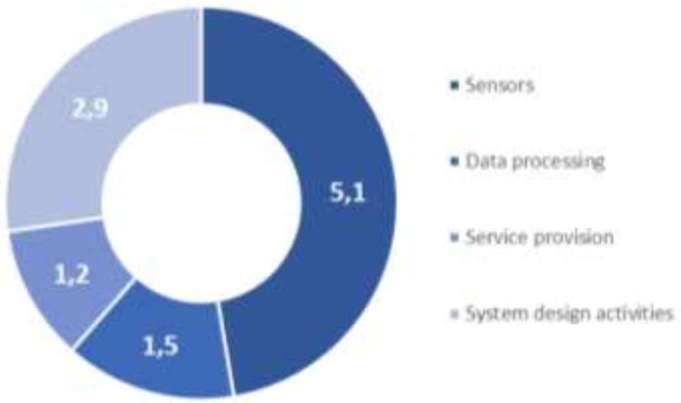
- Evolve **data processing capabilities** allowing a higher on-ground / on-board autonomy to **mitigate risks from the space environment** for European space infrastructure

- Develop **new EU SST services** enhancing the safety, security and sustainability of space operations, and enabling a higher coordination among space operators (**space traffic coordination**)

Budget (2-3SST18-20 grant)

- Strong involvement of the EU MS+SatCen:
  - **+300 total persons/months staff effort** for R&D
  - System design activities
  - Subcontracts management and coordination
- Subcontracted activities (01/2020 – 03/2022):
  - Total amount of **10,7 M€**
  - **Involving industry, academia and start-ups**

R&D subcontracts budget repartion (M€)

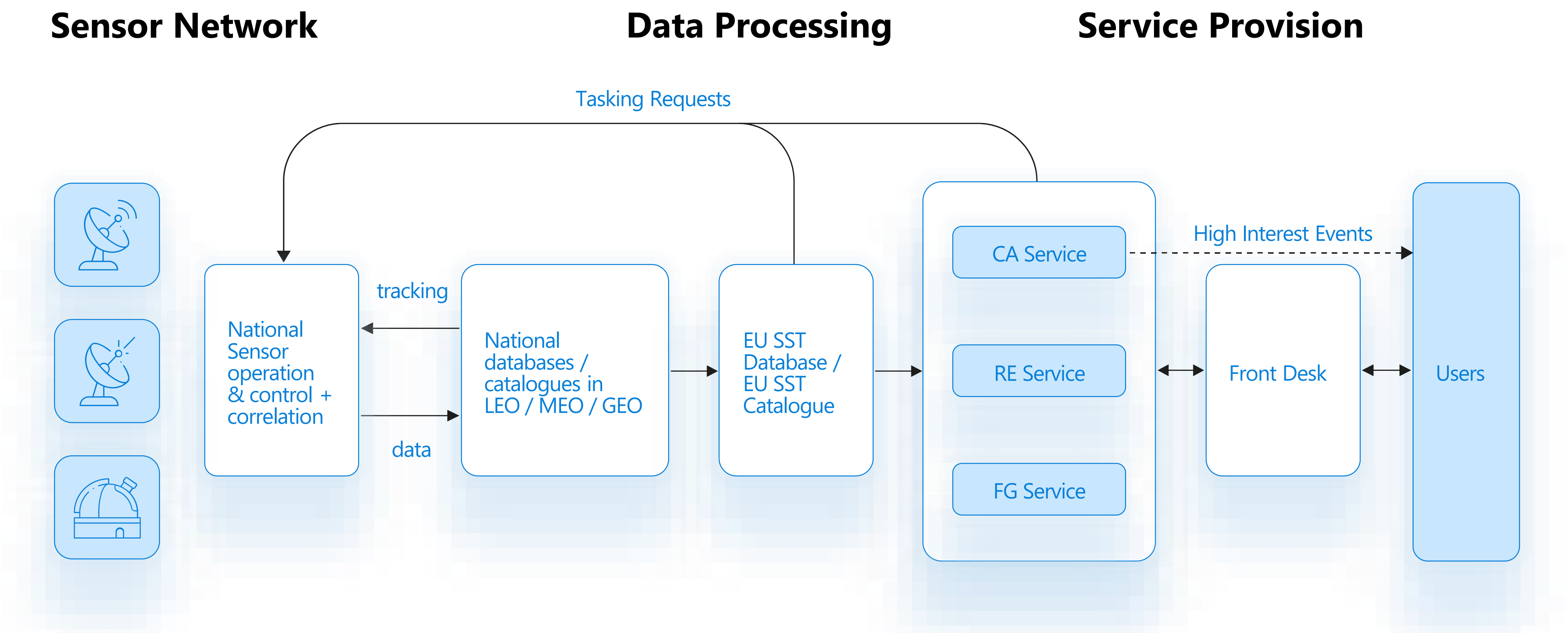


Subcontracted activities

Leading entity	Topics
DLR	• Horizon Scanning
CDTI	• Passive ranging technique • Data processing • New services • Architecture simulations and systems design
CNES	• Orbital population • Image processing and cataloguing, data fusion • Use of passive RF sensors • Low cost space based space surveillance constellation • Characterisation and propagation for data processing and services • Initial Orbit Determination and correlation in presence of high modelling errors • Collision risk algorithms for constellations, low relative velocity and correlated conjunctions • Automated collision avoidance mission • Architecture, performance and system studies • Continuous added value analysis • Adaptative Optics to detect and characterise spacecraft anomaly
ASI	• WFoV telescopes and SW development for HLEO surveillance • Commercial operators telemetry data
INAF	• Software update for the new configuration of BIRALES
PTMoD	• Future Space environment studies and new services • Conservative forces

This presentation does not intend to be exhaustive but to give an overview of activities

EU SST service provision model



EU SST R&D activities: studies on sensors

Vincent Morand, SST Cooperation
5 October 2021

Studies on sensors

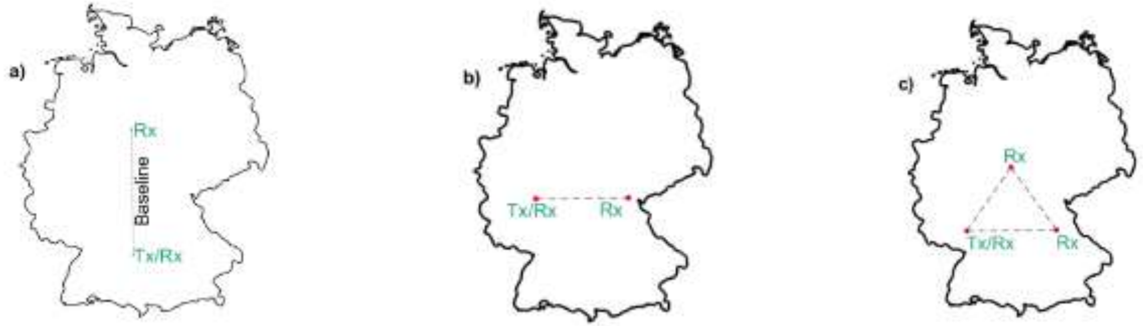
- **Sensor layer is a key building block of the EU SST architecture** since it provides the measurements (observations of resident space objects) to be used to build and maintain the catalogue and to provide the services

- The studies cover a **wide range of techniques**
  - Radars
  - Ground based optical sensors
  - Space based sensors
  - Lasers
  - Passive ranging

Studies on sensors - Radars

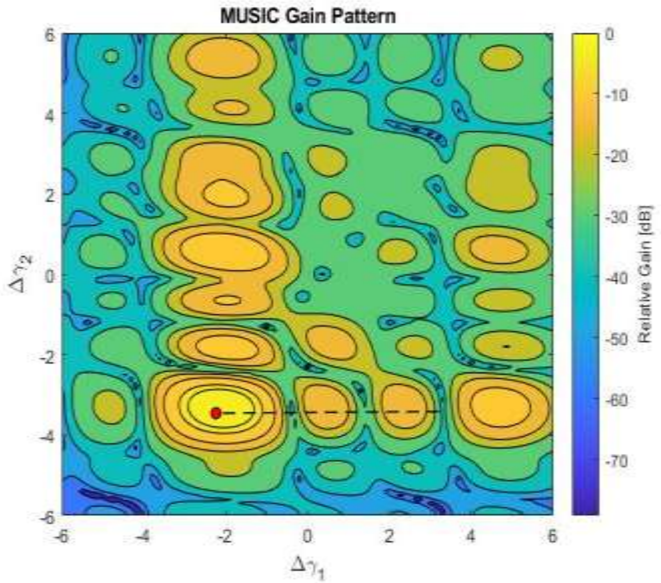
- **Current radar limitations**, in particular but not limited to the minimum detectable size, are one of the primary source of the current gaps in the services provision for the LEO regime

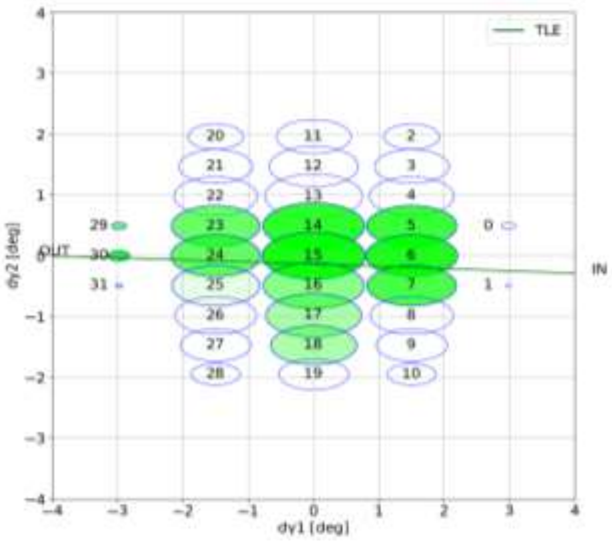
GESTRA distributed sensor architecture



Fraunhofer
FHR

BIRALES dynamic beamforming

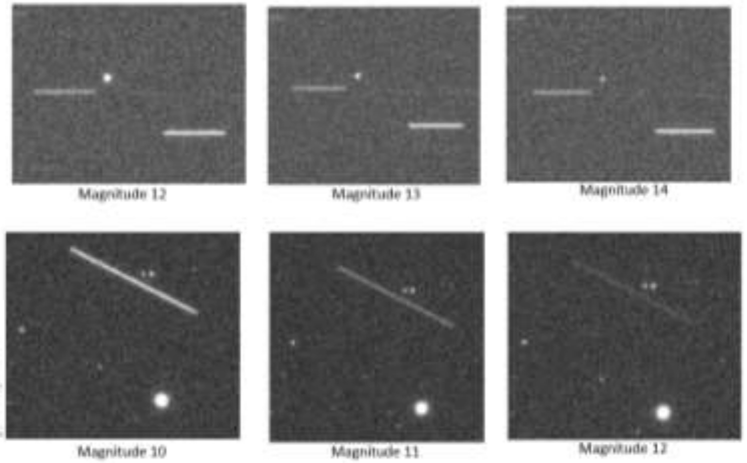




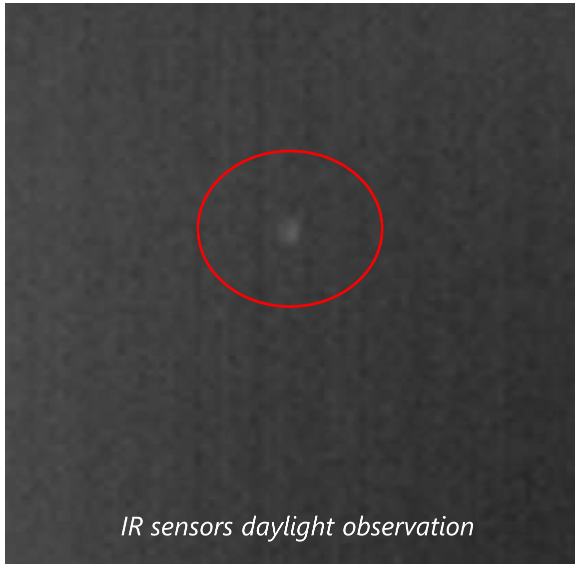
POLITECNICO
MILANO 1863

Studies on sensors – Ground based optical sensors

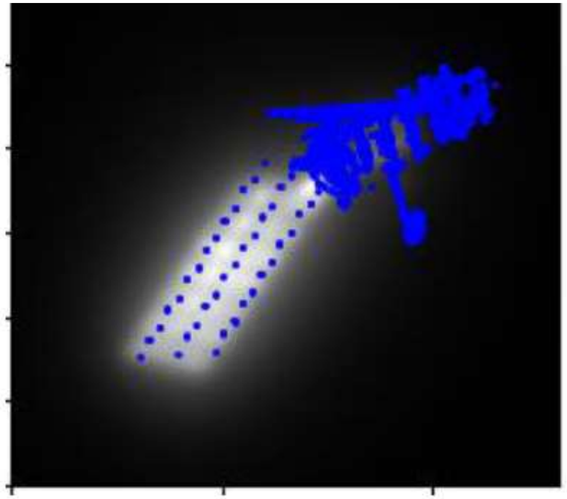
- R&D activities focus on
  - **Maximising the performance of existing capacities**: optimised surveillance strategy, improvement of image processing algorithm
  - **Exploring modern techniques**
- On going studies example:
  - Surveillance strategy for WFoV telescopes → **Dedicated presentation by OHB Italy**
  - Detection capacities: Multi-regime observation, machine learning techniques…
  - Use of **Infrared sensors, Adaptative Optics,…**



Multi-regime observations



IR sensors daylight observation



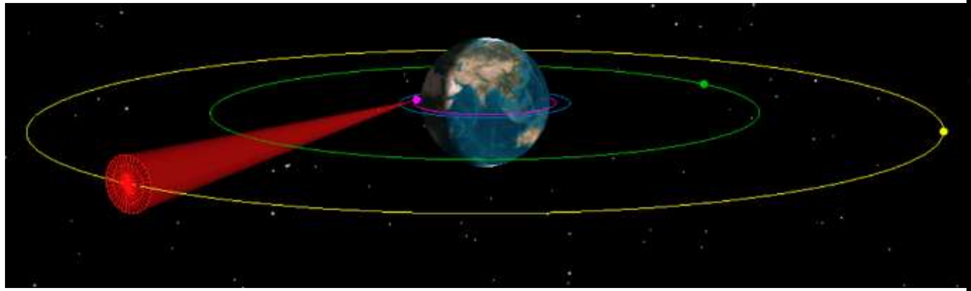
Adaptative Optics. Credits: ONERA

Studies on sensors – Space based sensors

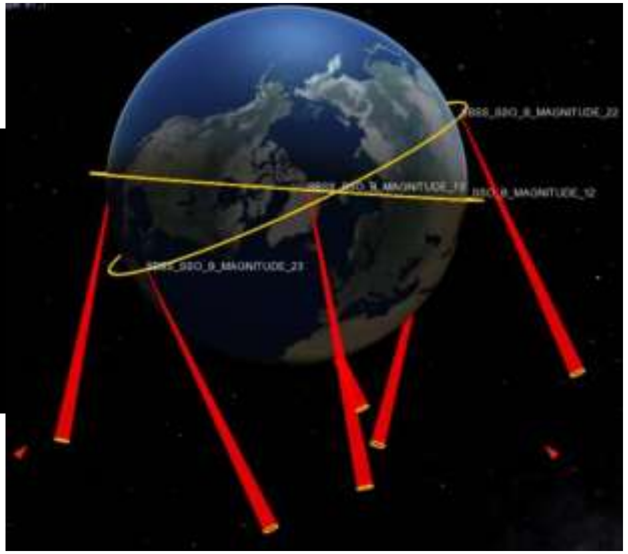
- **Space based assets are a promising candidate for complementing ground-based architectures**

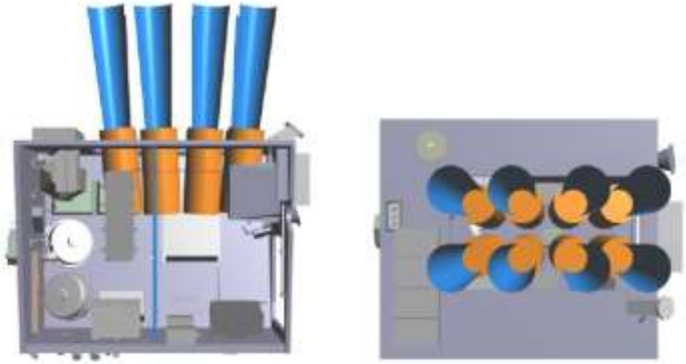
- Ongoing study for the design of a **Space-Based Surveillance System (SBSS) constellation**
  - Investigate the added value in **complement to the EU SST ground segment**
  - Define, simulate and select the **mission concepts showing best value for money** (design-to-cost approach)

Design of a SBSS constellation



ThalesAlenia Space



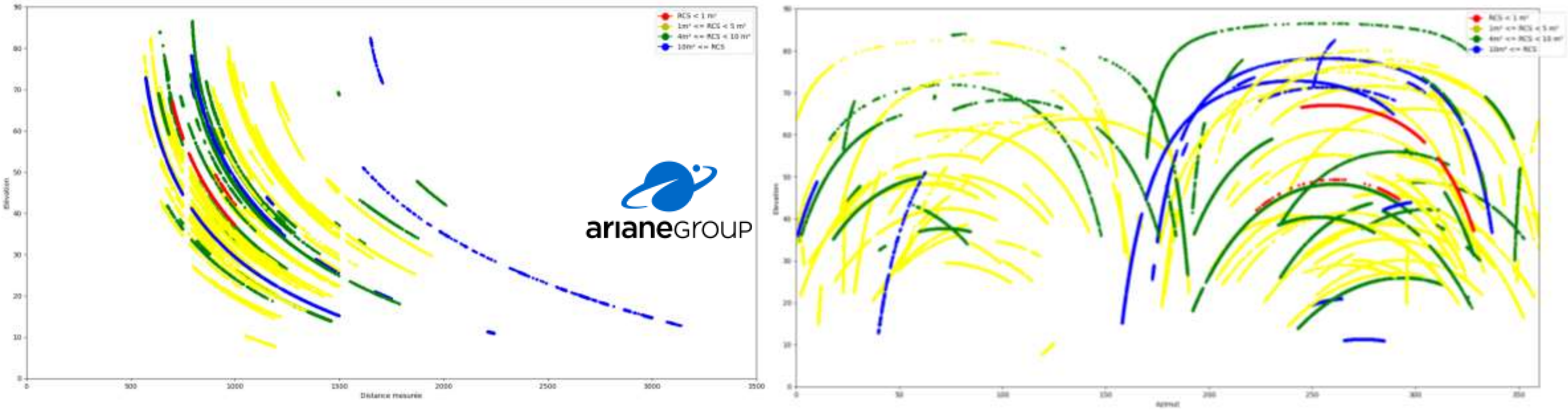


AIRBUS

Studies on sensors – Lasers

- **Satellite laser ranging** provides very accurate range measurements for space objects

- Ongoing study to solve important challenges for SSA applications:
  - **Non collaborative observations** (objects with no retro-reflectors) of small objects
  - **Daylight tracking** (observation outside terminator periods)



Non collaborative observation laser experiment

Studies on sensors – Passive ranging

- **Passive radio frequency sensors** take advantage of satellites RF emissions (TMCU, …) to achieve **high accuracy localisation** of active satellites

- Passive ranging has high potential to **support the services in all orbital regimes**

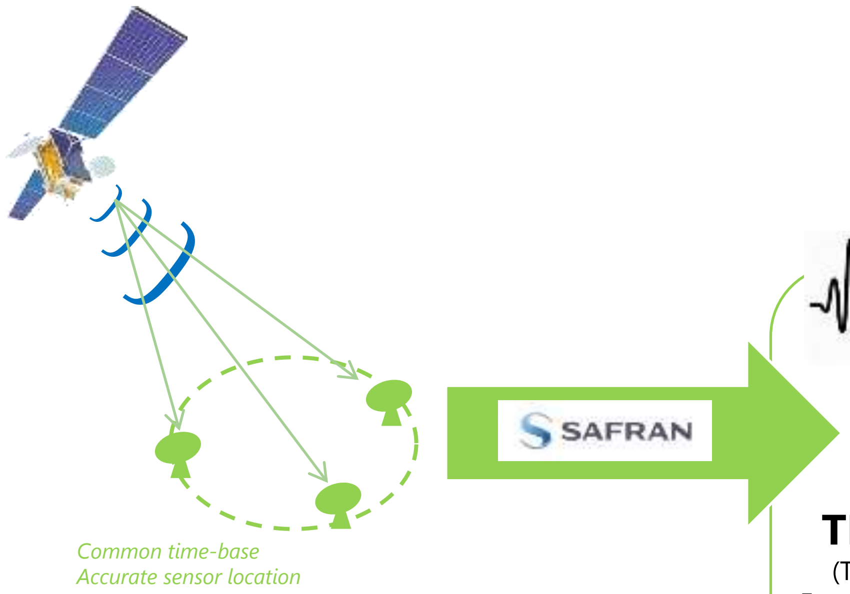
- Two ongoing studies
  - Study on passive ranging measurements handling in operating centres and for CA service provision
  - Exploiting passive RF sensors for non GSO → **Dedicated presentation by SAFRAN**

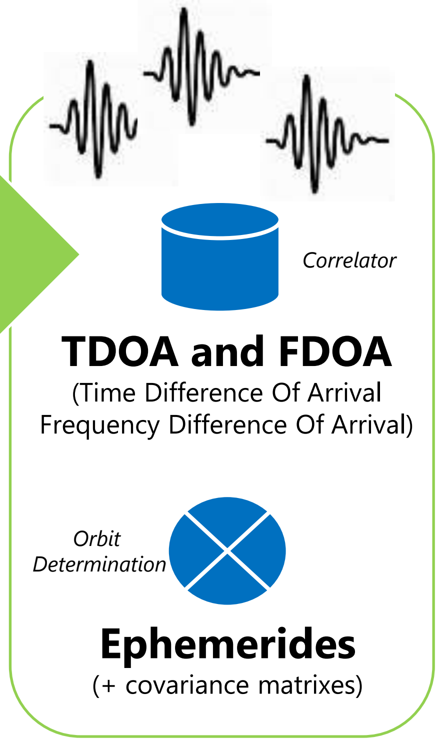
Passive RF Sensor for NGSO

Baptiste Guillot (SAFRAN), WeTrack / SEE Product Manager
5 October 2021

Context

- Most spacecraft transmit RF signals
- Signals are received by several synchronised sensors
- Signals are processed in control centre to produce observations -> TDOA & FDOA
- Automatic Orbit Determination maintains a continuous catalogue with trajectory, manoeuvres and outliers identifications



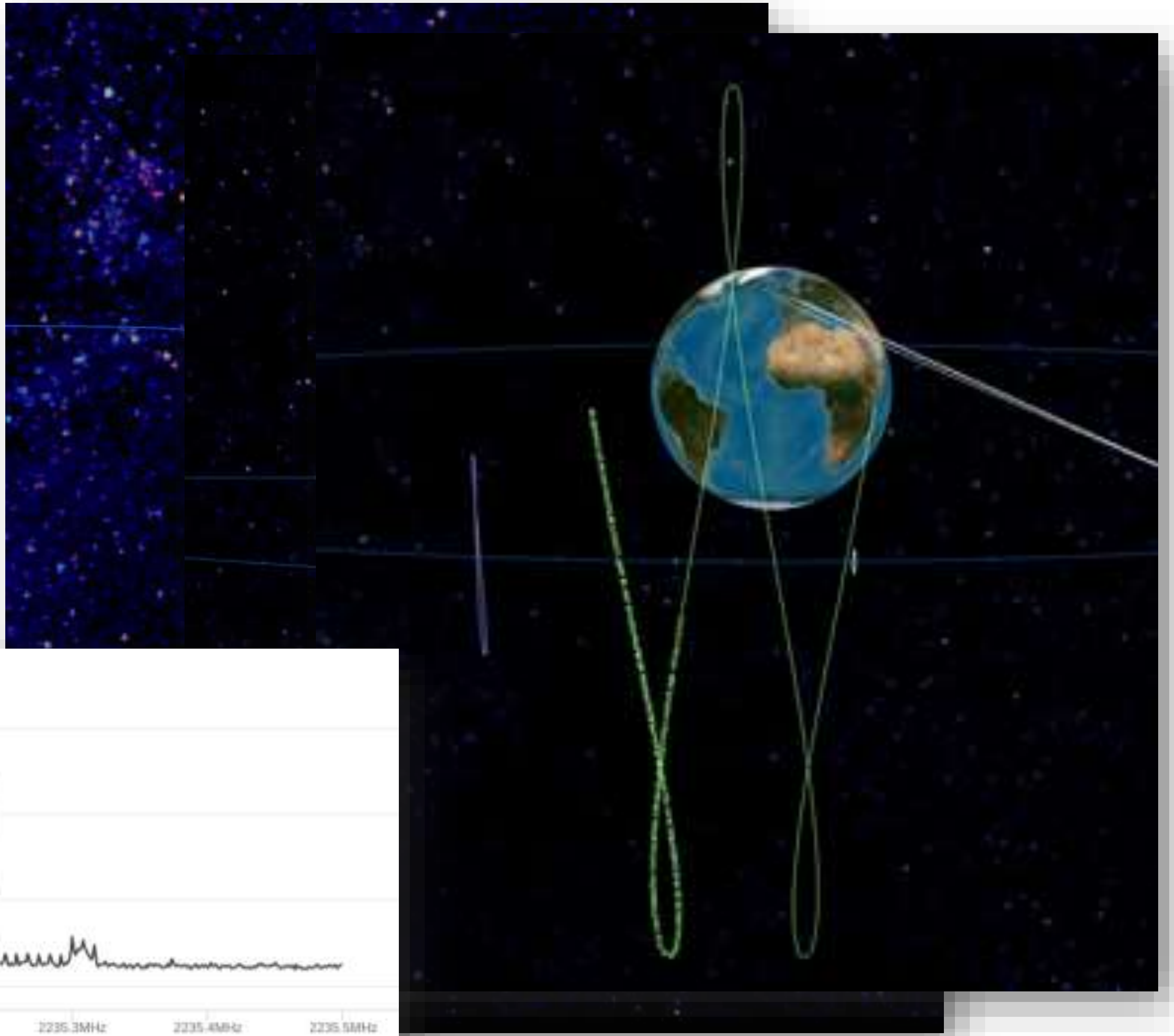


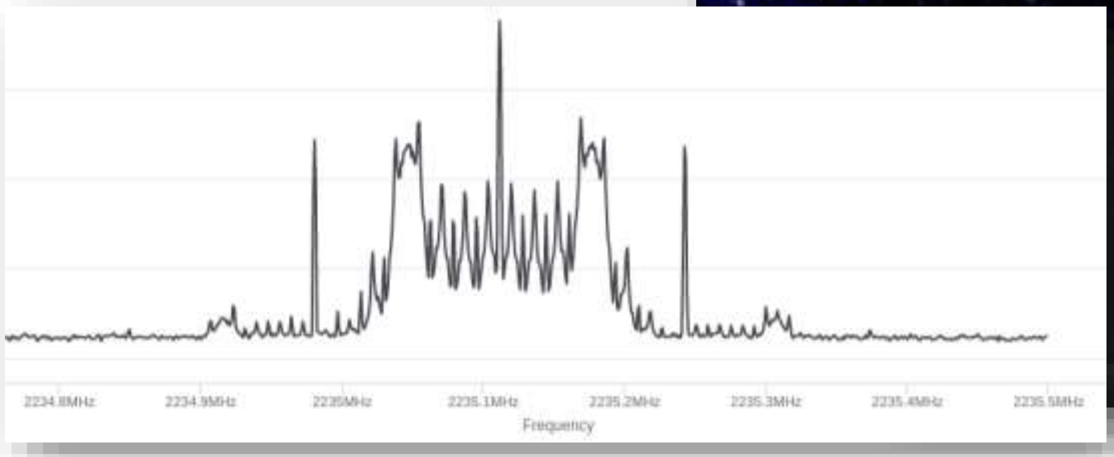
Currently, SAFRAN hosts and operates WeTrack

The 1st global GSO Satellite Passive RF Tracking Network

Passive RF Sensor – Key features

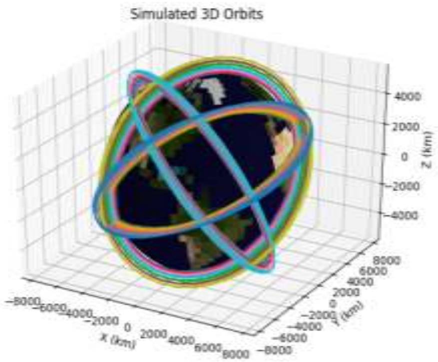
- Works Day and Night
  - High revisit: 30 min. typ./5 min high-rate
- Continuous measurements allow accurate manoeuvre characterisations
- No cross-tagging in close approach
- Works with high velocity targets
- RF signals helps object identification

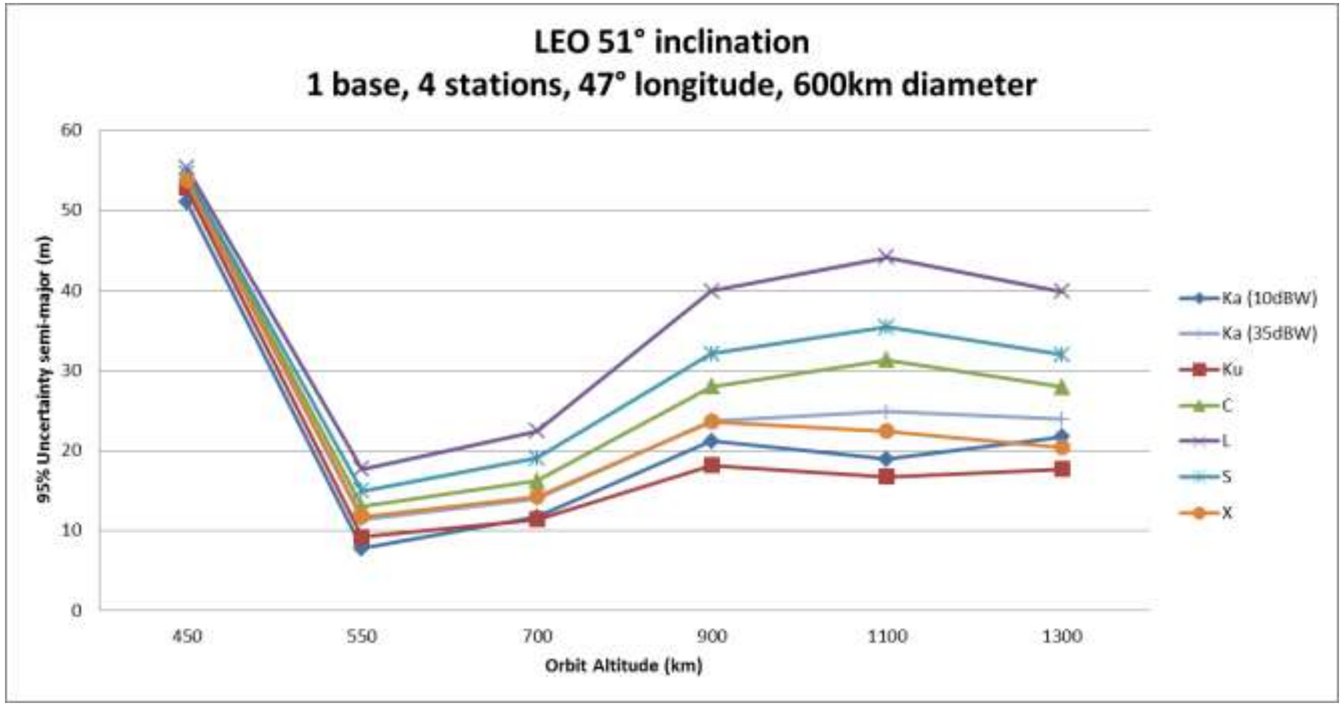




Passive RF Sensor for NGSO – R&D activities

- **Main objective:** to demonstrate and assess the performance of Passive RF tracking on **Non-GSO (NGSO)** satellites (LEO, MEO, LEOPs)
- RF Sensor accuracy had been forecasted by previous SAFRAN/ESA ARTES study (ex: LEO 51° -> uncertainty < 60m (3 sigma))
- Sensor network is highly scalable
  - Performances can be improved by adding stations
  - Or adapted to targeted missions (SSO, Constellations…)





Passive RF Sensor for NGSO – R&D activities

- Sensor upgrade:
  - Antenna positioner upgrade to fast and full motion
  - Allowing to point towards any visible target
  - Optimised for multi-target obs. collection
- Software upgrade:
  - LEO, MEO, LEOP pointing integration
  - Adapted signal processing for high-speed target high accuracy TDOA/FDOA (Time Difference Of Arrival / Frequency Difference Of Arrival) production

Passive RF Sensor for NGSO – Preliminary outcomes

- Preliminary outcomes @MEO (Altitude: 20200km, GPS & BEIDOU):
  - Successful in continuous tracking and TDOA/FDOA generation of GNSS Satellites (S-Band)
  - Orbit Determination on MEO Beidou with only **2 stations** had already reached **cov < 35m (1 sigma)**
  - Measurements noise < 5ns (in line with GEO performance)

- Preliminary outcomes @LEO (Altitude: 1340km):
  - Initial TDOA/FDOA production engine operational (visibility pass scheduler, LEO-specific signal processing adaptation)
  - Awaiting setup of the full operational prototype (October 2021) for initial OD results and performance assessment

Passive RF Sensor – Future steps

- Ongoing tasks:
  - 4-station NGSO capable prototype network roll-out (Q4 2021)
  - Validation campaign on S-Band with well-known satellites as references
  - Validation campaign on Ka-Band (Telecom-constellation tracking use case)

- What's next?
  - Sensor scheduler efficiency improvements (AI algorithms, optimisation…)
  - Manoeuvre tracking on non-continuous observations
    (continuous improvement based on current experimentation RETEX)
  - SST & SSA NGSO RF Tracking business cases & practical scenario investigation
    - Collaborative/Non-collaborative situational assessment
    - Constellation tracking
    - Multi-sensor collaborations (RADAR/Electro-optical/RF) for improved accuracy and fidelity

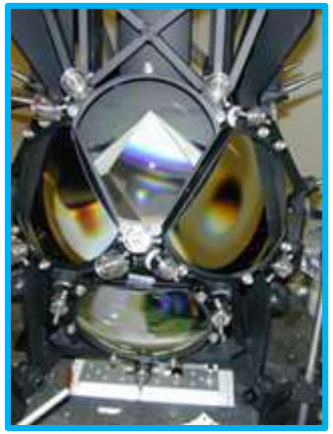
Wide FoV telescopes

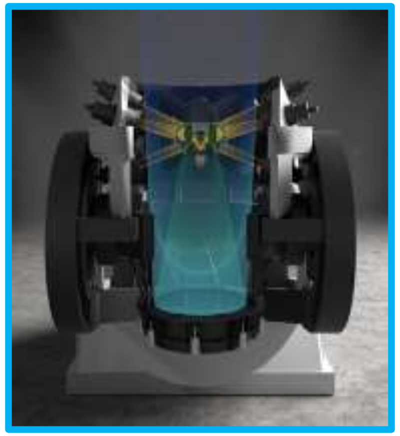
Dr Francesco Cerutti (OHB Italia), BU Telescopes

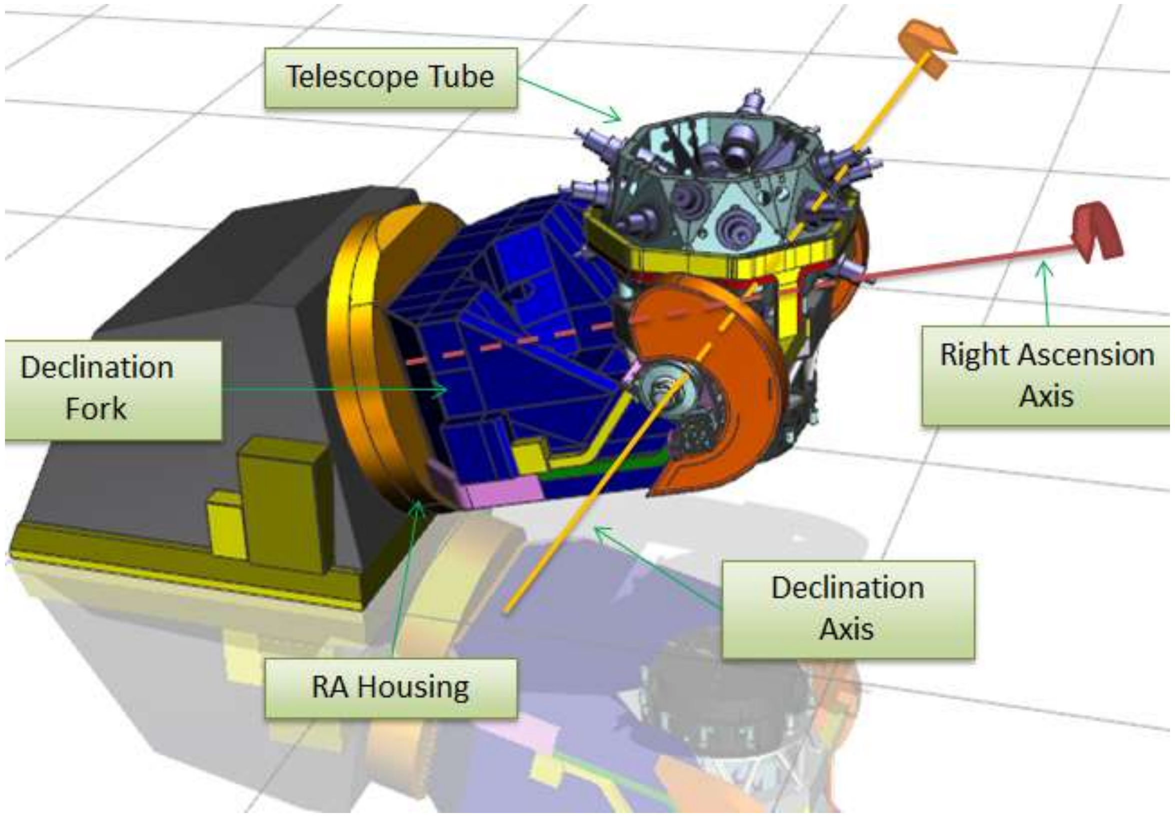
5 October 2021

The sensor: Fly-Eye Telescope

- One meter class optical sensor: 450nm – 770nm
- Innovative optical design (Fly-Eye)
- First prototype installation in Matera (2022)
- Developed for SST survey and debris detection
- Very Wide FoV (44sq deg) with high dynamic capability (7 deg/s)
- Flexibility: from LEO to GEO depending on Network Architecture and Obs. Strategy







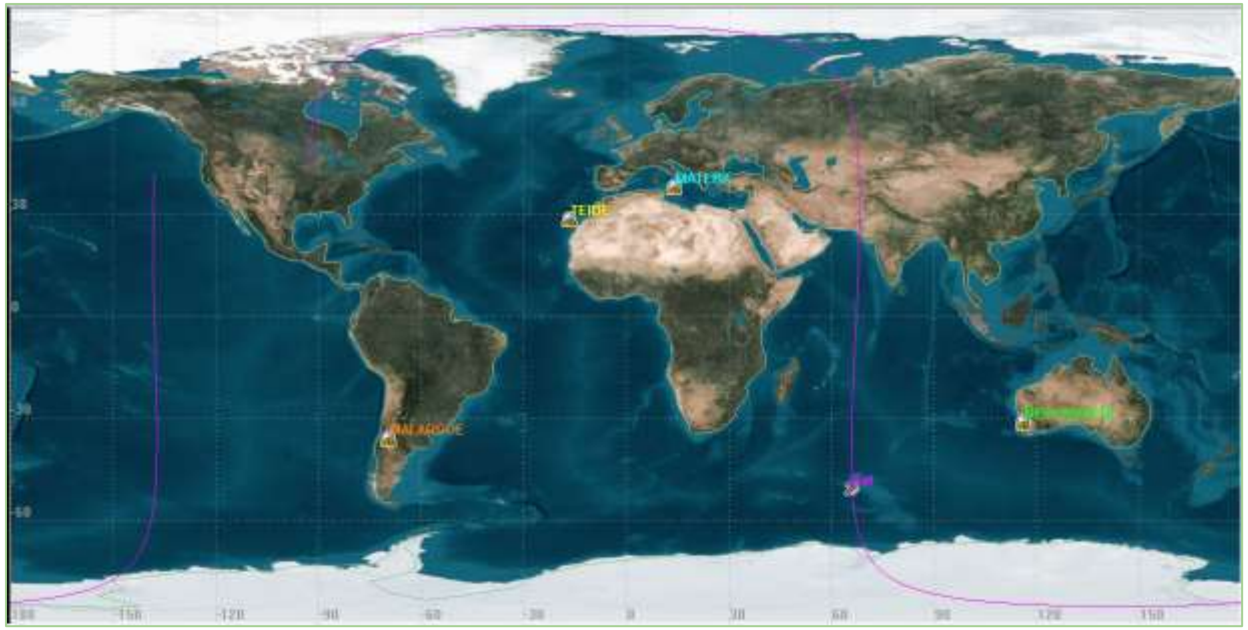
SUrvey TElescope for Debris detection (SUTED)

Objectives and expected outcomes:

- demonstrating the possibility to build up a catalogue of dangerous MEO objects
- reduced number of sensors: a ground network of 4 Fly-Eye telescopes
- high cataloguing efficiency for MEO objects
- trail Signal to Noise Ratio (SNR) ≥ 6

Background:

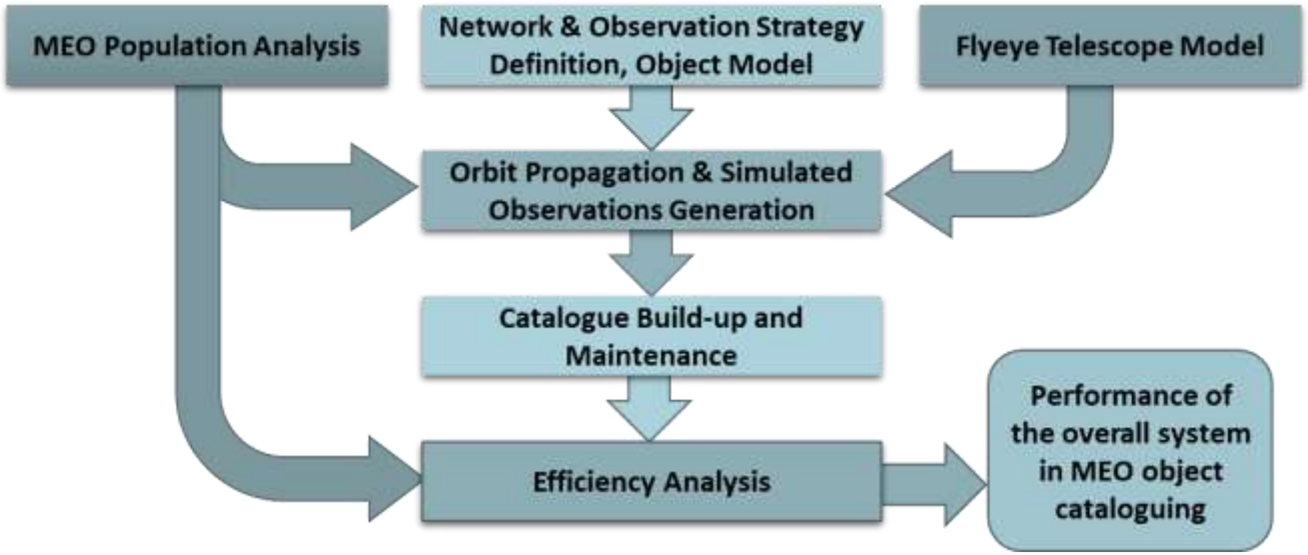
- July 2020 - February 2021
- OHB Italia involved as prime
- SpaceDys involved for what concerns Data Processing (orbit determination and catalogue build-up)



Station	ID	Latitude [deg]	Longitude [deg]
MATERA	Z01	37.867773° N	14.023047° E
TEIDE	Z02	28° 18' 03.3'' N	16° 30' 42.5'' W
NEW NORCIA	Z03	31° 02' 54.0'' S	116° 11' 31.0'' E
MALARGUE	Z04	35° 46' 24.0'' S	69° 23' 59.0'' W

SUrvey TElescope for Debris detection (SUTED)

- SUTED study has demonstrated that:
  - **100%** of GNSS-like MEO objects are successfully discovered and catalogued within 2 months
  - **+96%** of all MEO resident objects are successfully discovered and catalogued within 2 months



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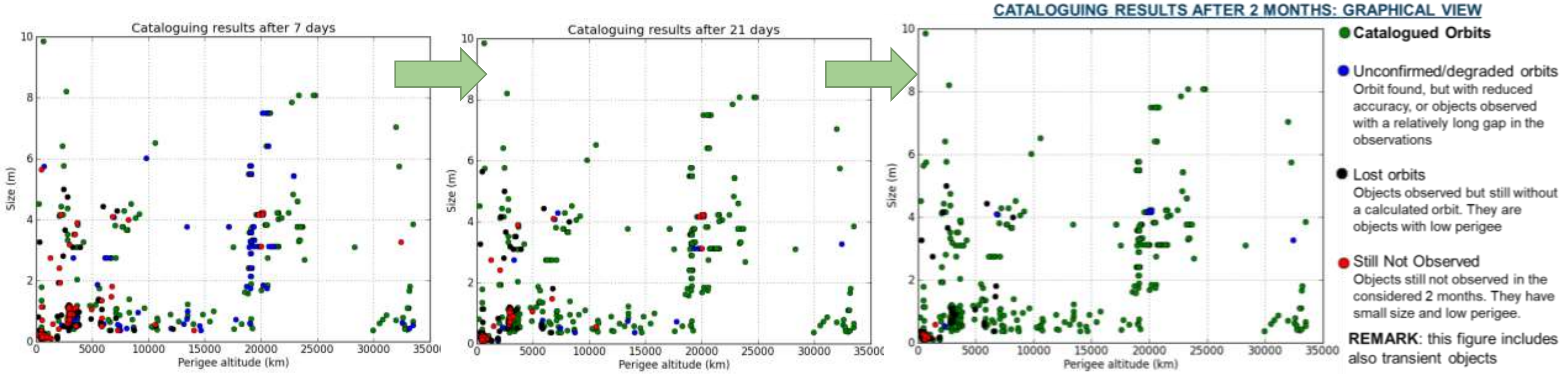
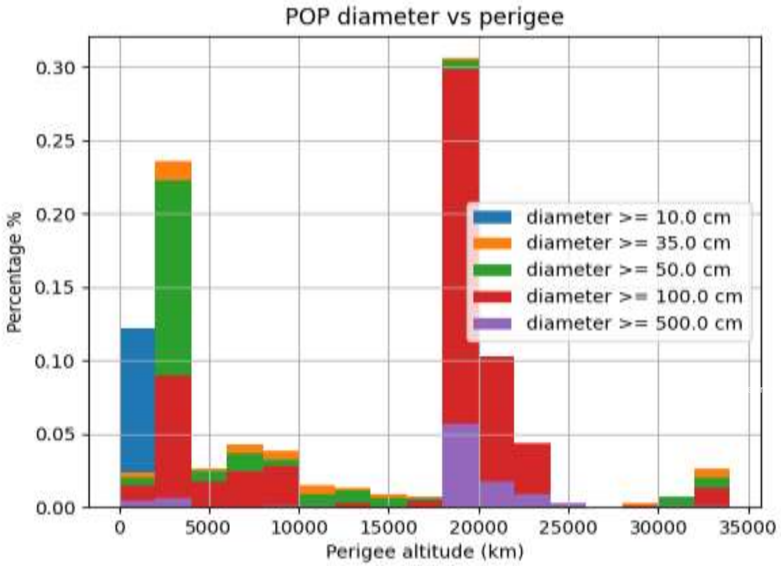
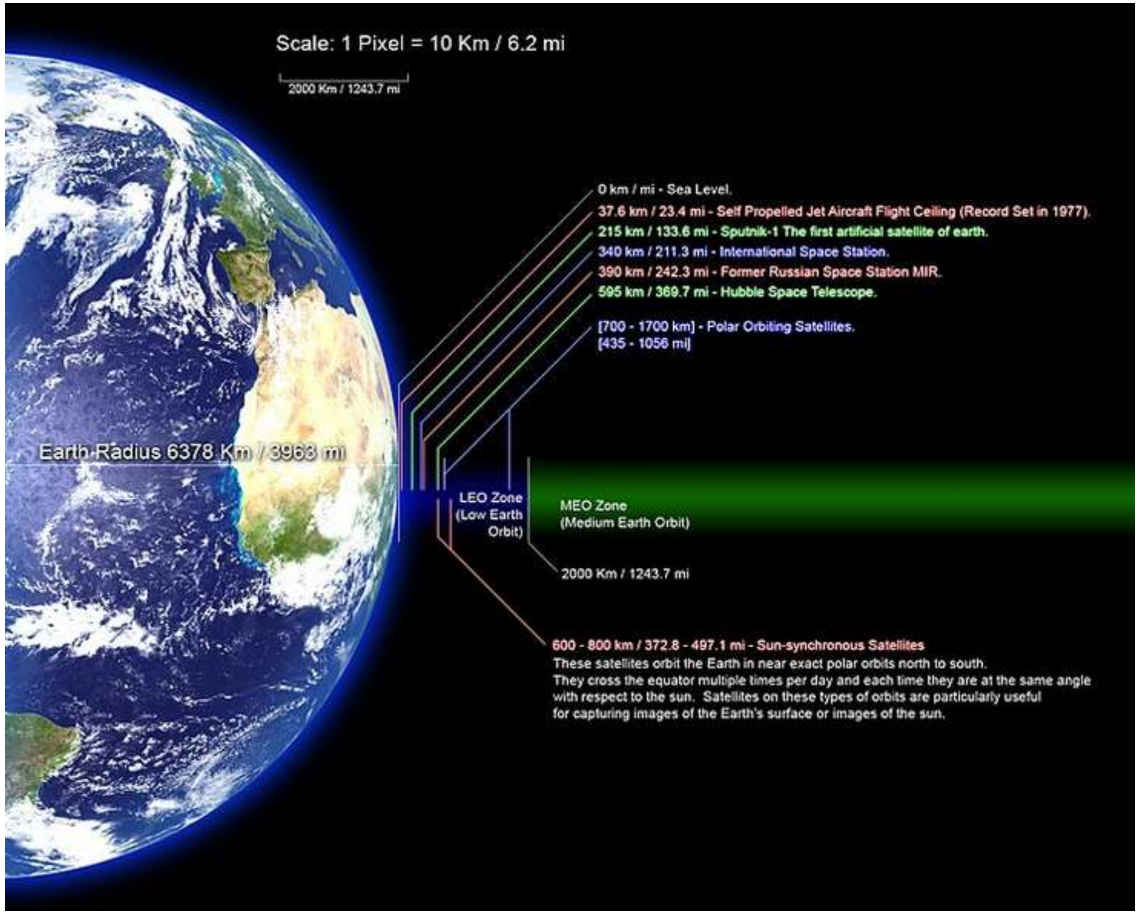


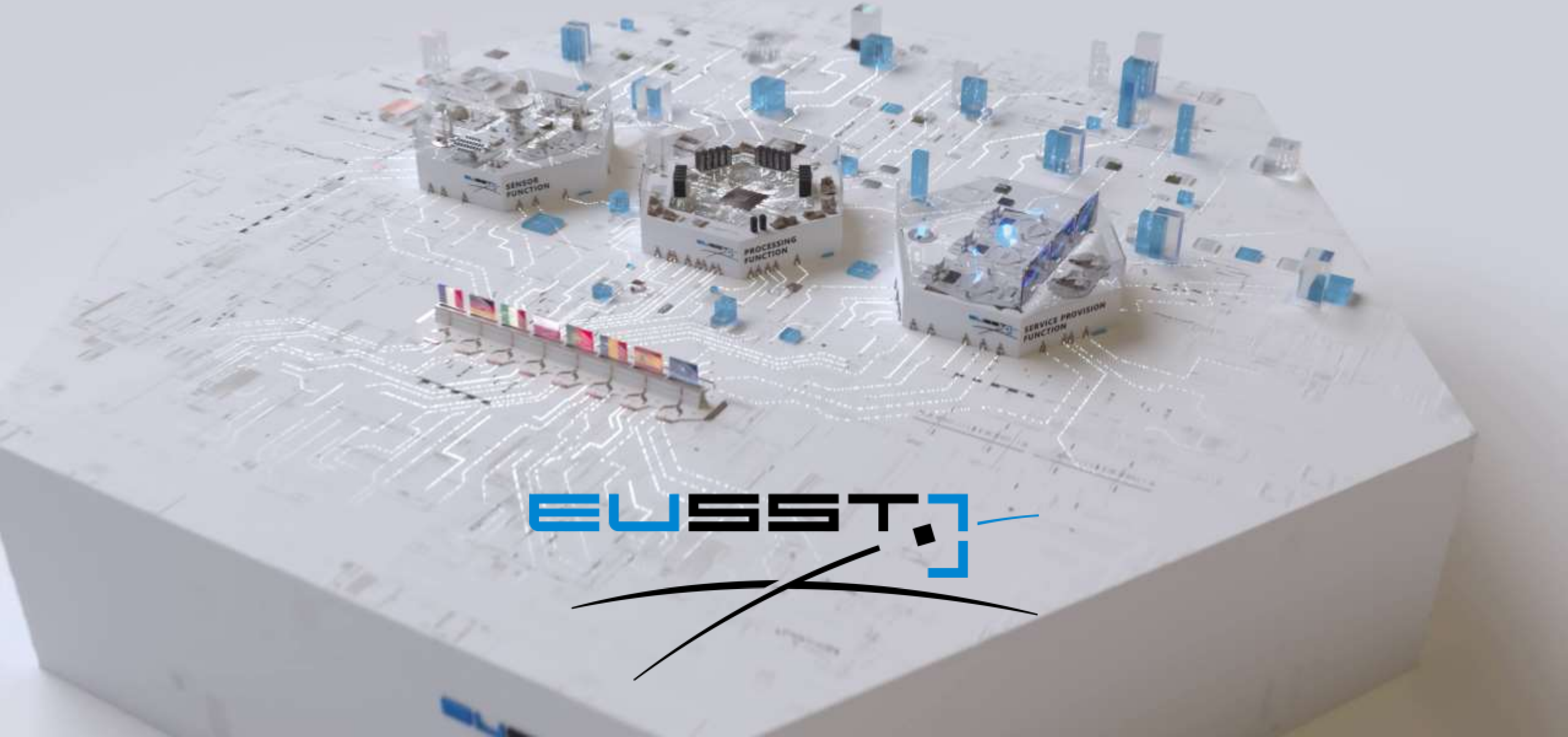
Future steps: H-LEO Surveillance with Fly-Eye

- The new *«H-LEO surveillance with Fly-Eye telescope»* study will focus on the buildup and maintenance of a catalogue of High-LEO objects using a network of Fly-Eye Telescopes
- A study logic similar to the SUTED study will be implemented
- The efficiency of the whole process (Observation, Detection and Orbit Determination) will be analysed





Q&A session


SENSOR FUNCTION
PROCESSING FUNCTION
SERVICE PROVISION FUNCTION

EU SST R&D activities: studies on data processing

Vincent Morand, SST Cooperation
5 October 2021

Studies on data processing

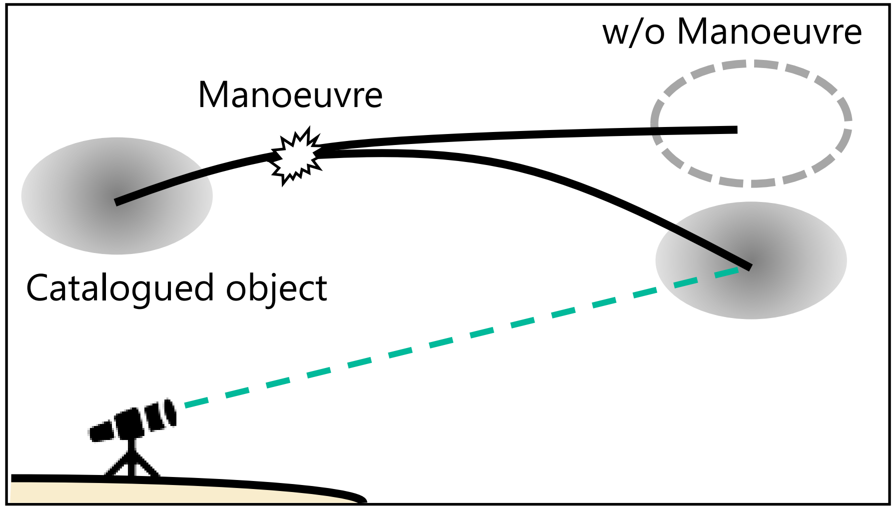
- The data processing layer aims to **maximise the quantity and quality of information and products** that can be derived from the measurements provided by the sensor layer

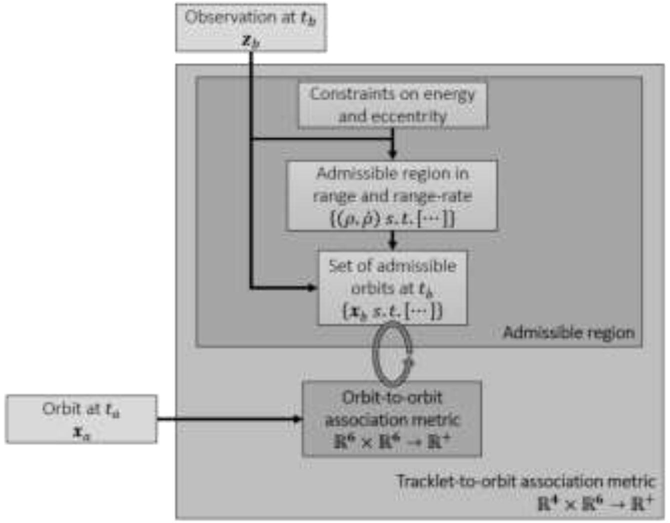
- The studies cover a wide range of topics:
  - Improvement of **correlation and IOD methods**
  - Improvement of **uncertainty characterisation and propagation**
  - **Data analysis** (historical data, telemetry data), trends and quality control

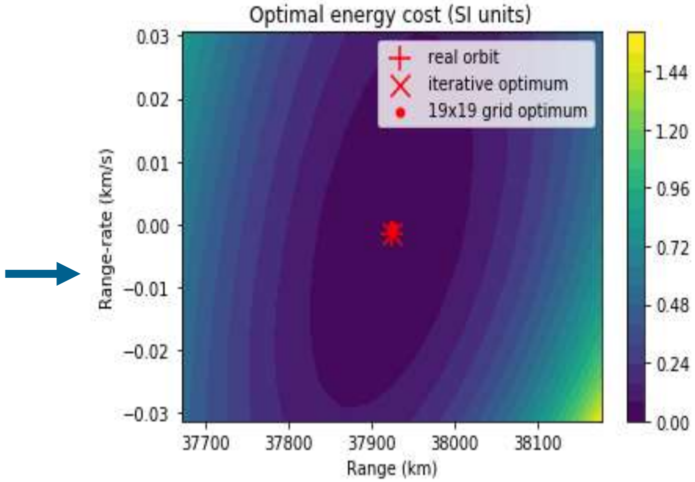
- In particular, **manoeuvring objects are challenging**
  - Correlation of the measurement to the manoeuvring object
  - Detection of manoeuvring capacities of a secondary object in a conjunction

Studies on data processing

- Correlation and IOD methods
  - A fundamental step for catalogue maintenance is to **successfully associate new measurements to catalogued objects**
  - But what happens if the object has manoeuvred and it is no longer where we expect it to be?
    - **False negative** in the correlation: object state is no longer updated and the catalogue loses custody of the object
    - **Uncorrelated tracklets (UCTs)** are generated: a “new” object initialised



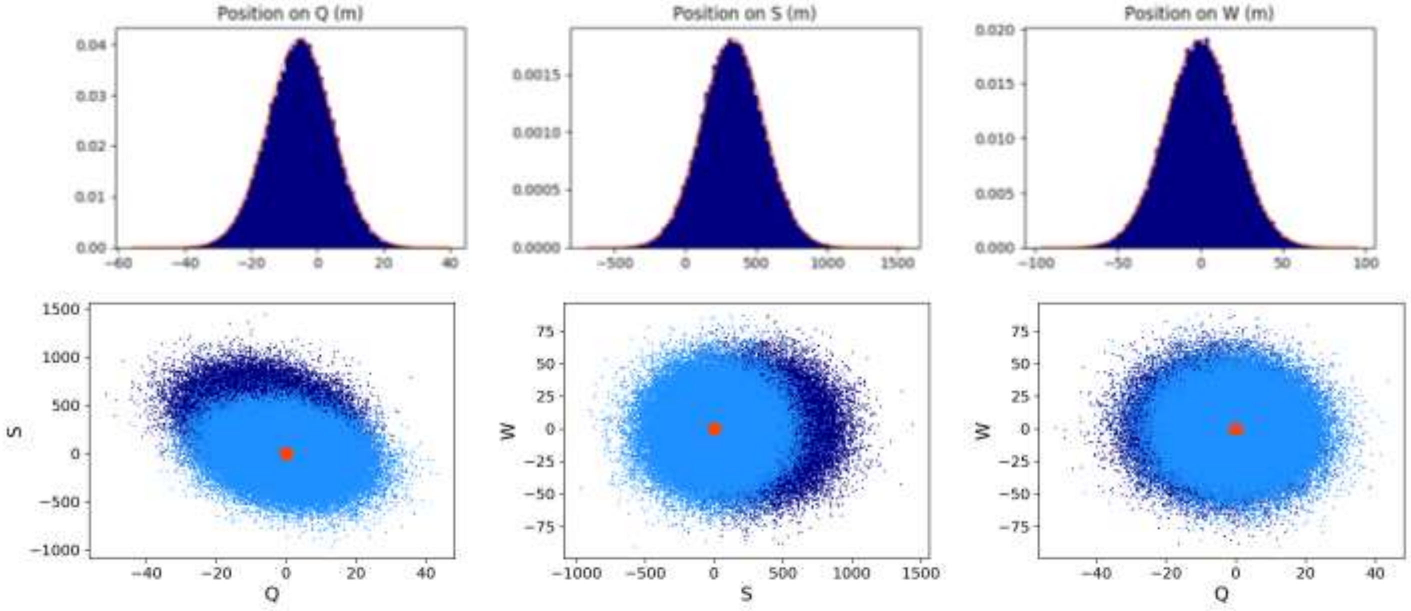




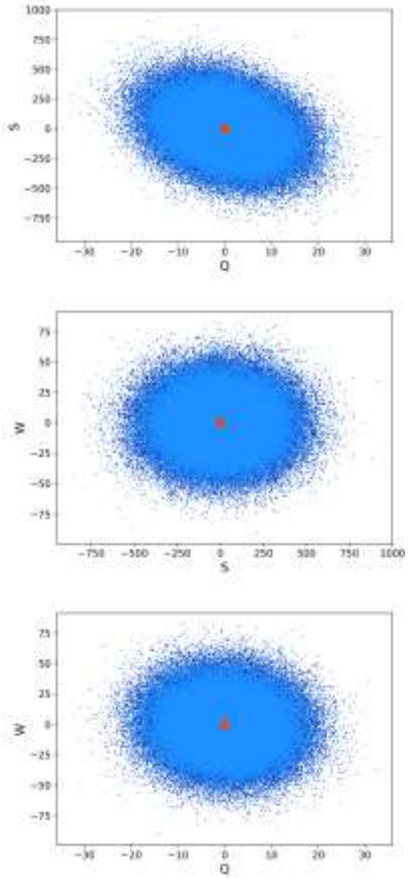
Optical correlation for manoeuvring satellites

Studies on data processing

- Uncertainty characterisation and propagation
  - How to deal with non-Gaussian uncertainties?
    - Frame transformation, Gaussian mixture…
  - How to propagate the uncertainty efficiently?



Considering manoeuvre errors in STM propagation



Uncertainty propagation considering manoeuvre errors

S3TOC data analysis tools

Francisco Simarro (gmv), SST section project manager
5 October 2021

Context

- Project duration: **approx. 1 year**
- Main contractor: gmv
- Development of three tools for **historical data analysis, trends** and **quality control**:
  - **Sensor** data analysis tool (SNMS)
  - **Cataloguing** data analysis tool (CATANA)
  - **CA Service** data analysis tool (CASTA)
  - Additional tool developed for **2D/3D geo-referenced data** visualisation (visualGRef)
- Timespan for data analyses: from 2017 to September 2020
- **First analysis and conclusions** on the trends
- Precursor for advance **techniques of machine learning** and **artificial intelligence**

Context

S3TOC started operations

- **Sensors:** 5
- **S3T Catalogue:** ~300 ob. (GEO)
- **Services:** National CA users, RE, FG

2016

2018

S3TOC & French OC specialised in CA Service

- **Sensor network:** 6
- **S3T Catalogue:** ~400 ob. (GEO)
- **CA Services:**
  - 2 users
  - 9 sats.
  - ~100 proc. CDMs/day
  - ~80 new CA events/day

2020

Data Analysis Project

- **Sensor network:** 9
- **S3T Catalogue:** ~1000 ob. (GEO)/~1500 ob. (LEO)
- **CA Services:**
  - 15 users
  - 100 sats.
  - ~1800 proc. CDMs/day
  - ~150 new CA events/day

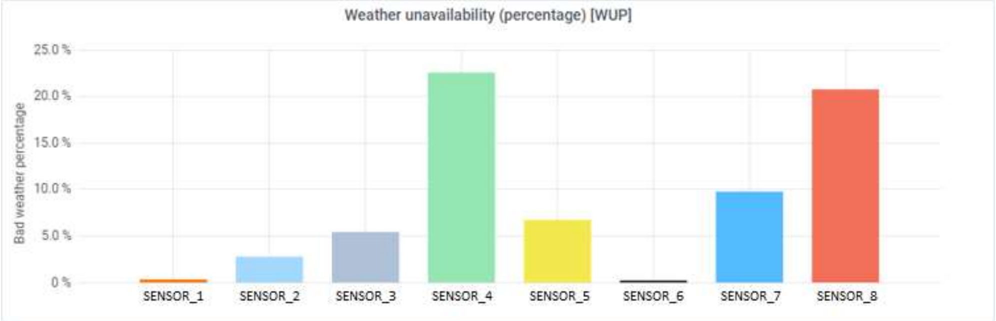
Now

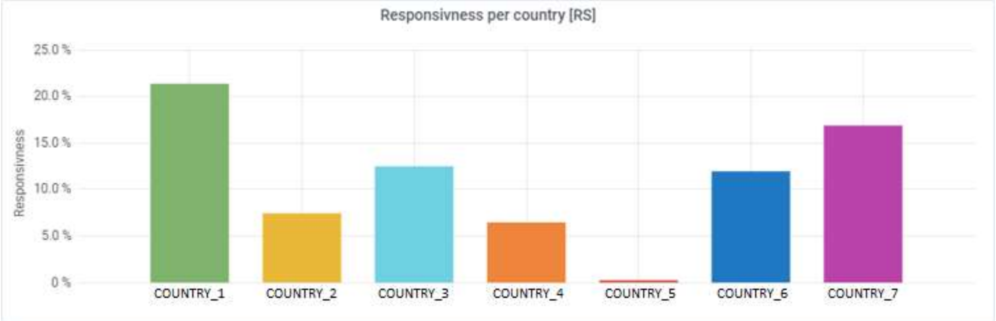
- **Sensor network:** 43 (EU SST-SN)
- **S3T Catalogue:** ~1700 ob. (GEO)/~5000 ob. (LEO)
- **CA Service:**
  - Near 30 users
  - More than 250 sats.
  - ~2500 proc. CDMs/day
  - ~230 new CA events/day

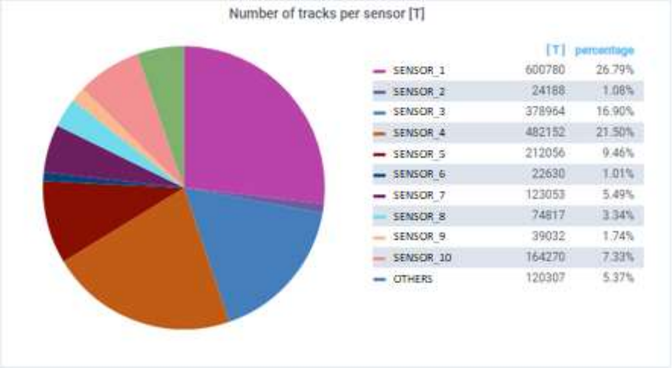
New upcoming services

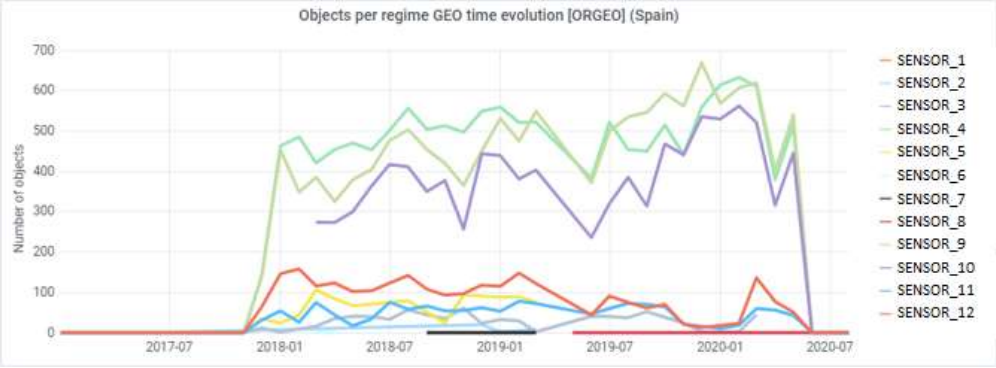
Data analysis tools

- **Sensor data** analysis tool (SNMS)
  - **Accuracy**
  - Nb. and rate of **tracks/observations**
  - Nb., size and regime of **objects** observed
  - **Timeliness**
  - **Responsiveness** etc.
- Generates **sensors report** to be reported to EU SST
- Monitors **sensor performances**



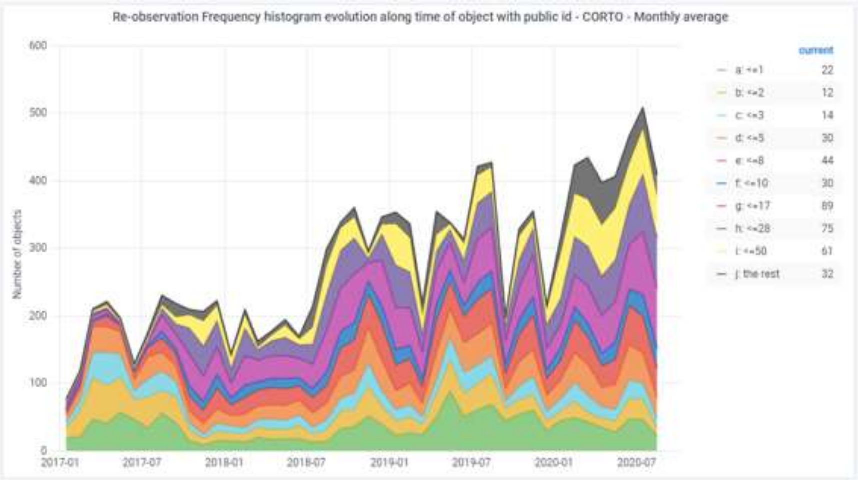


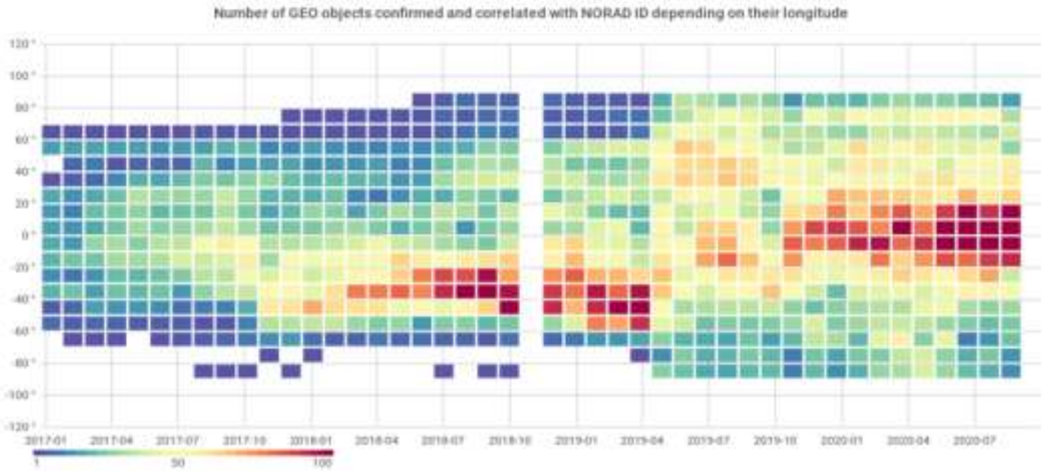




Data analysis tools

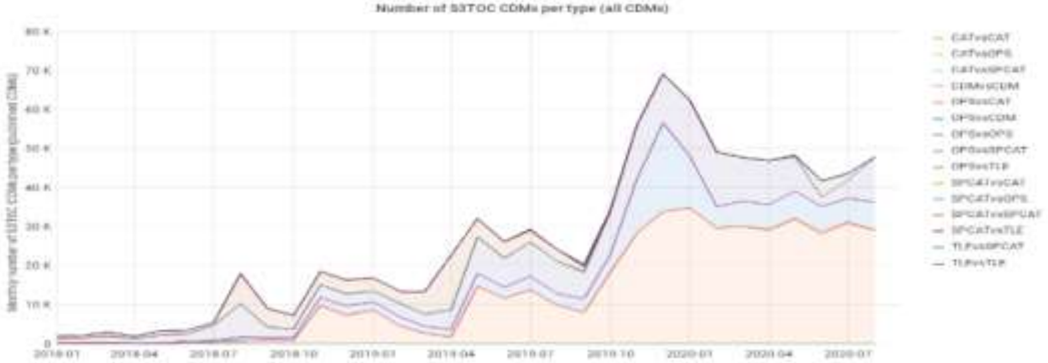
- **Cataloguing data** analysis tool (CATANA)
  - **Correlation**:
    - to public catalogue
    - to S3TOC catalogue
  - **Cataloguing**: SW performances
  - **Catalogue quality**: statistical comparison versus SPCAT
- S3TOC **cataloguing chain quality control** subsystem

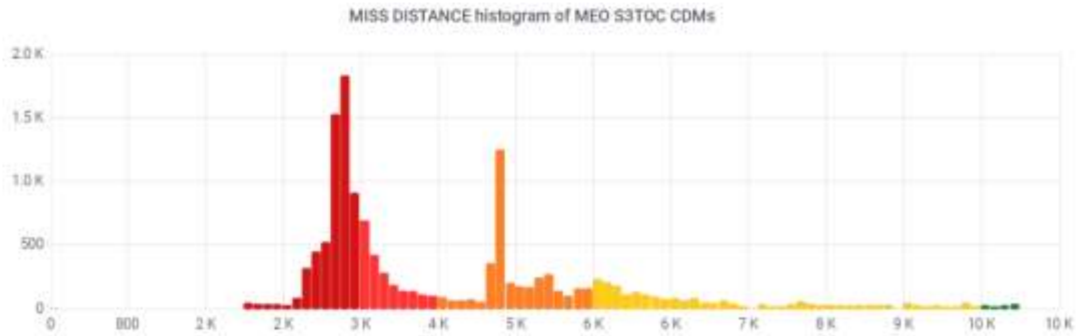


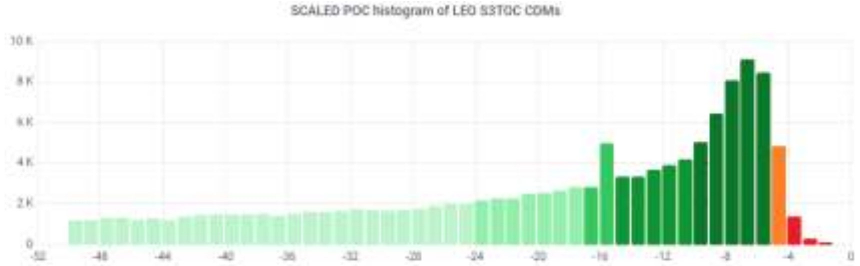


Data analysis tools

- **CA Service data** analysis tool (CASTA):
  - Quantitative analysis of **CDMs/CA events**
  - **Trend analysis** on conjunction variables
  - Introducing **quality** of a CDM/CA event:
    - Stability of an event
    - Similarity between S3TOC/French OC/18th SPCS
- S3TOC **CA service quality control** subsystem
- **Real time** classification of CDMs/CA events

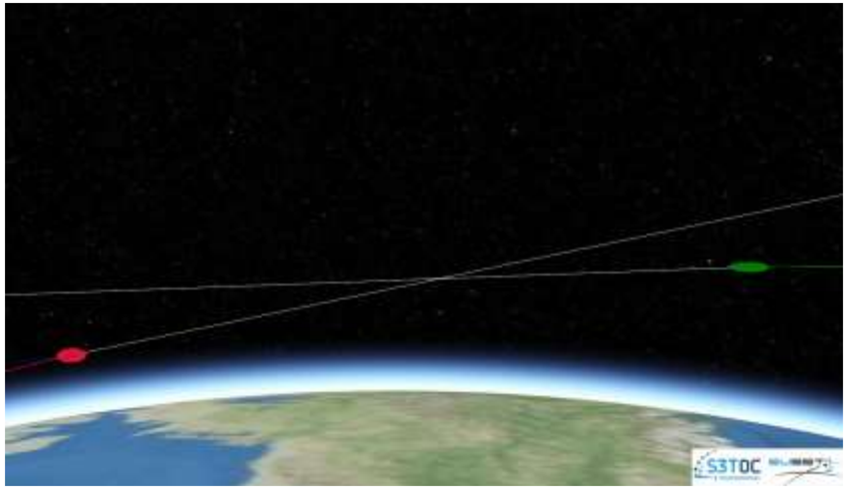


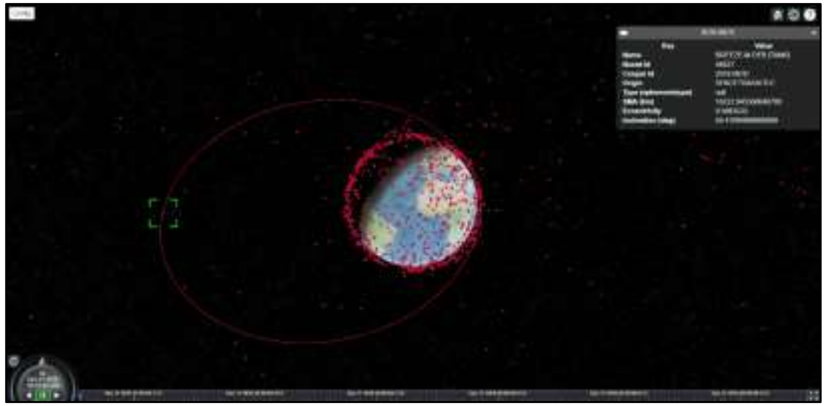


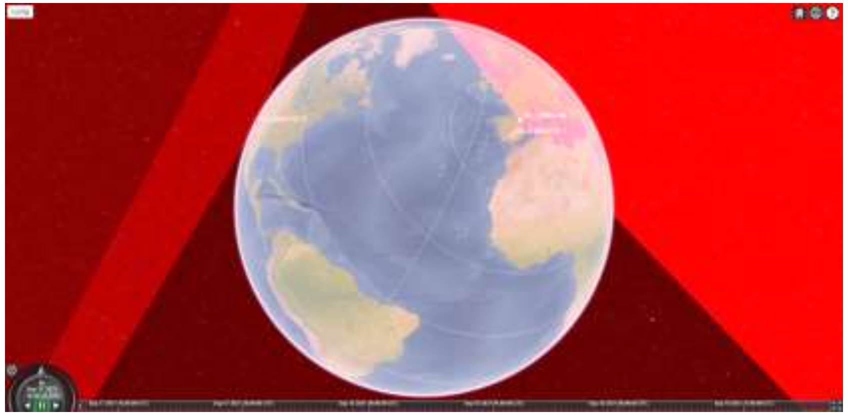


Data analysis tools

- Visualisation of **2D/3D geo-referenced data** (visualGRef)
  - Catalogue
  - Ephemeris
  - Sensors position and FoR
  - Conjunctions
- Facilitates analyst **comprehension**
- **Graphical resources** for publications and media



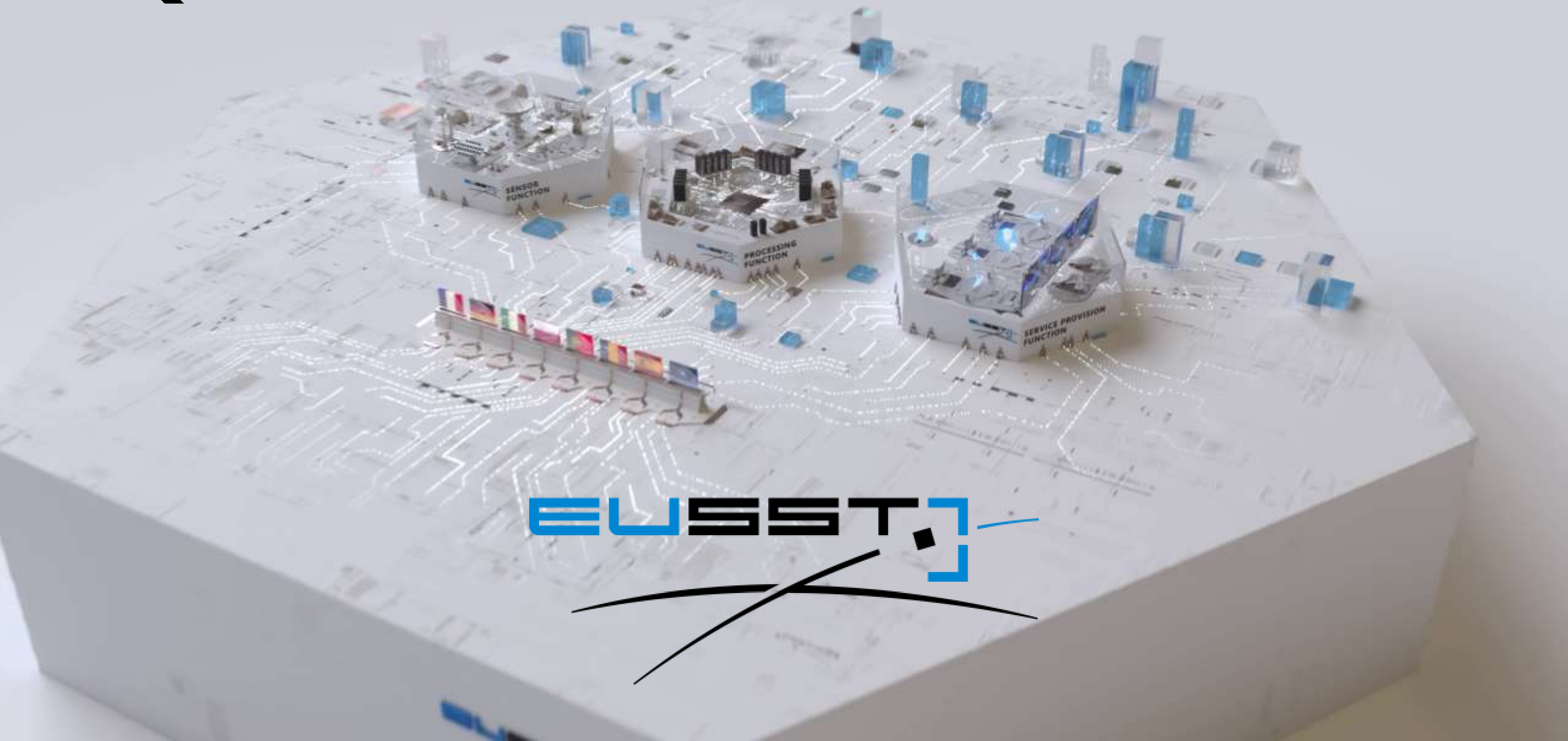




Future steps

- Proven to be very **powerful tools** to exploit data and to extract useful conclusions
- **Data continuously growing** in SST. **Constant review** becomes **crucial** to face **future challenges**:
  - Increasing nb. satellites (mega-constellation, etc.)
  - Growing debris population
  - More sensible sensors
  - Closer contact with users
- **Trend analysis** and **data mining tools** to maximise and **optimise capabilities** of the S3TOC
- Need to introduce **Machine Learning** techniques to optimise resources for data analysis
- Moving towards **CA service intelligent automation**!

Q&A session



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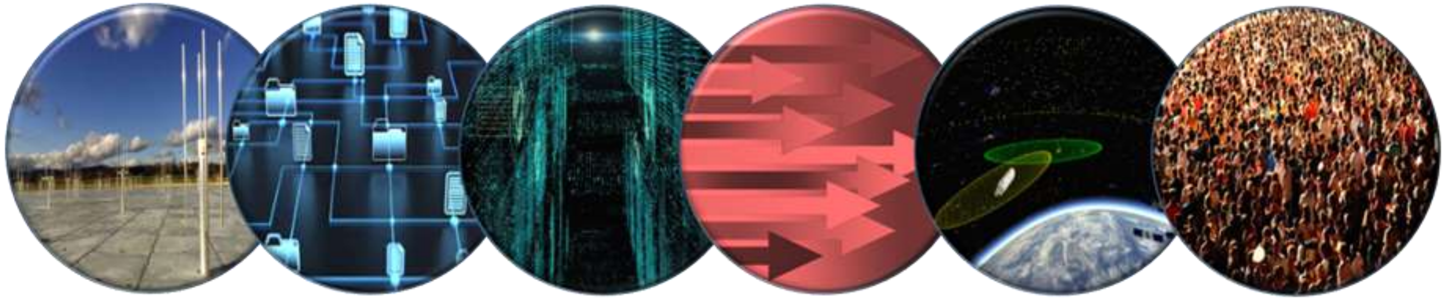
EU SST R&D activities: studies on service provision

Vincent Morand, SST Cooperation
5 October 2021

Studies on service provision

- The service provision is delivering products to users

sensors **data sharing** **database** **tasking** **services** **front desk / users**



+135
ORGS
23 EU MS

>240
Satellites

- The studies aims to:
  - **Improve the quality and efficiency** of the existing services
  - Anticipate and help the **emergence of new EU SST services**

8.5/10
Overall feedback

Studies on service provision

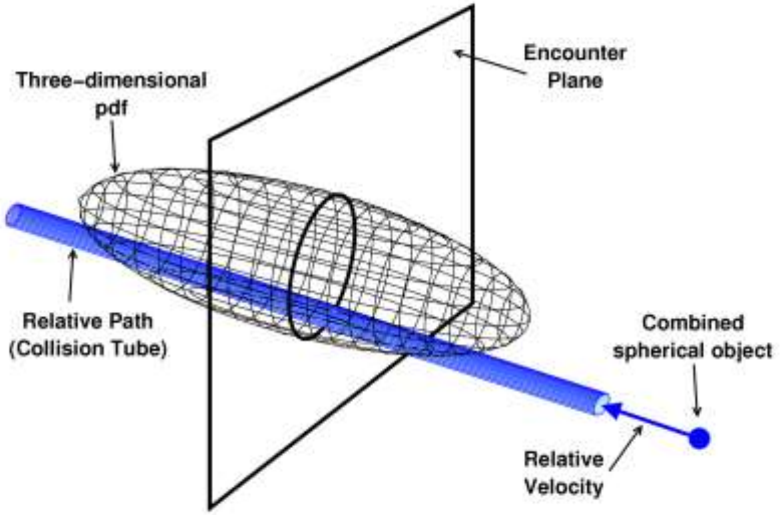
- Improve the quality and efficiency of the existing services
  - Improvement of the **computation of Probability of Collision** (non-standard cases, multi-objective)
  - Screening optimisation and detection of manoeuvres: **Share My Space**
  - Autonomous collision avoidance with Station Keeping: **Airbus Defence and Space**

THALES

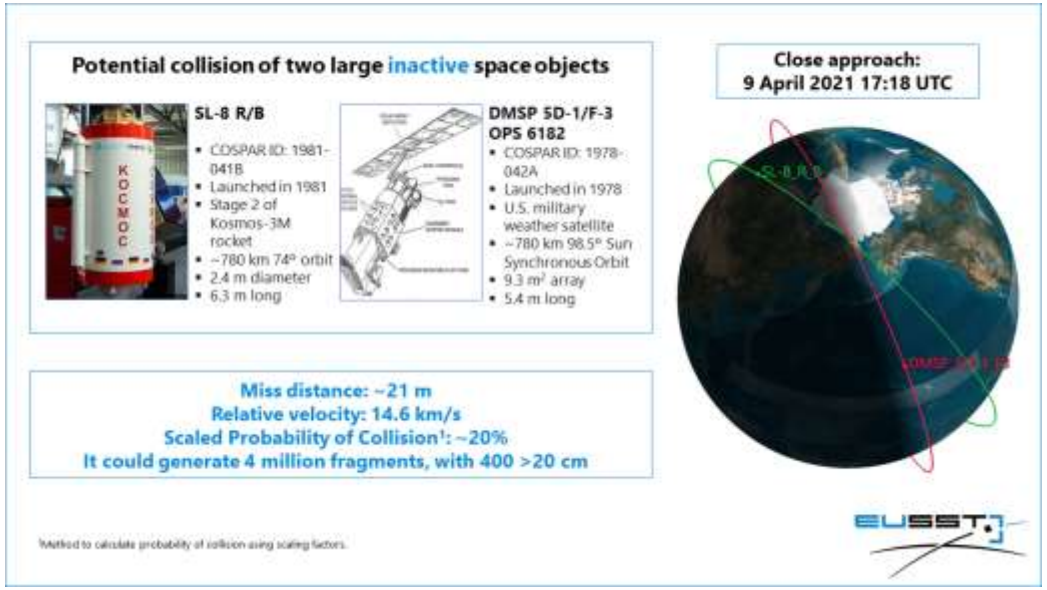
ThalesAlenia Space

LAAS CNRS

gmv INNOVATING SOLUTIONS



Probability of collision computation

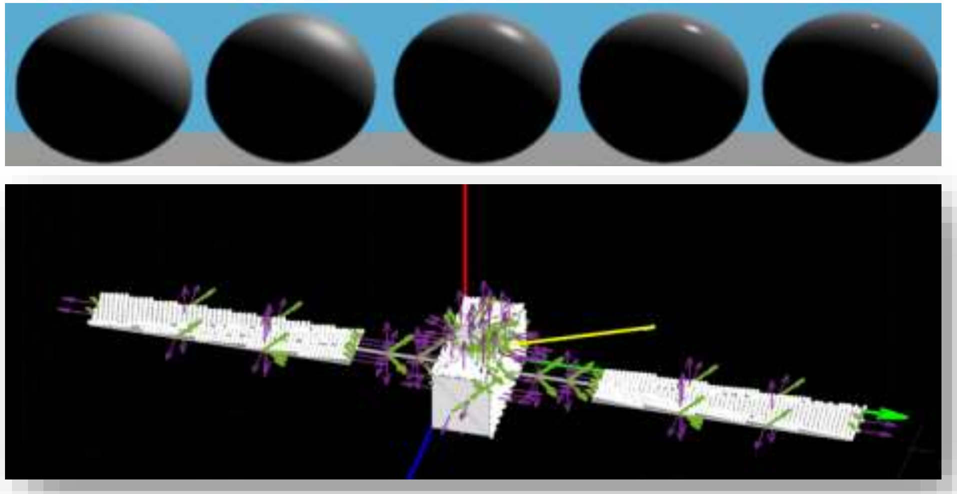


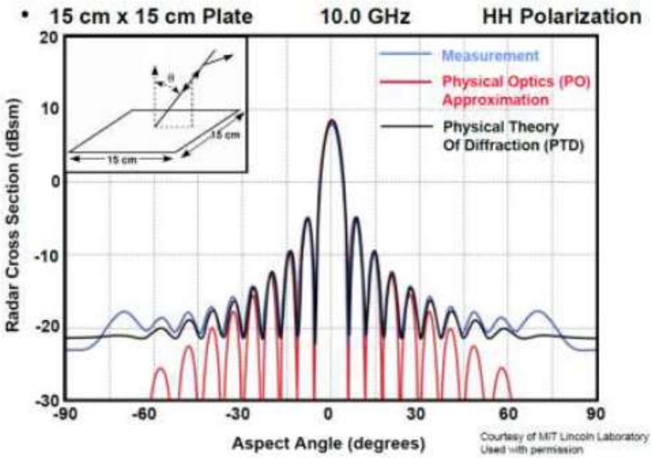
Large vs Large screening example

Studies on Service Provision

- Anticipate and help the emergence of new SST services
  - **Mitigation**
    - In-orbit contingency/anomaly support
    - Post-manoeuvre analysis and support to EOL, LEOP and EOR
  - **Remediation**
    - Support to Active Debris Removal and in-orbit proximity operations
  - **Radio Frequency Interference**

Attitude determination from data fusion





Autonomous collision risk management

Dr Romain Lucken (Share My Space), CTO & Co-Founder

5 October 2021

Automating collision risk management process

- From September 2020 to April 2022
- Scope
  - Enabling as much autonomation as possible in collision avoidance activities
- Study structure
  - **Test case definition**
  - **Automating secondary objects management: characterisation & classification**
    - Active & passive objects
    - Manoeuvring objects: detection and characterisation of manoeuvres
  - **Screening optimisation**
    - Using PATRIUS Library to generate ephemerides as well as SP ephemerides data
    - Developing a new algorithm to detect conjunction with 4 new filters in filtering-lib 3.2.0
    - CATCH Analytical method implemented. Re-screening vs 21000 objects in circa 1 min.
  - **Simulator definition and development**

Characterisation of secondary objects

- More and more conjunctions involve active satellites
- For these objects, ephemerides determined from ground observations and orbit determination are wrong in general because of orbital manoeuvres
- Two solutions:
  - Coordination between operators → preferred way but not always possible
  - **Manoeuvre detection and anticipation**
- Two manoeuvre detection software developed:

MANEXT TLE

- Typically based on public TLE
- Enhancing the method of Kelecy et al. (2007)
- Runs in 2 hours on 1 CPU for all the satellites over 6 months
- First estimate of the orbital manoeuvres

Manoeuvre anticipation is limited to regular station keeping patterns

MANEXT "SP"

- Cross propagation using the **Patrius** library (CNES open source) from virtually any accurate orbital state vector, in practice SP vectors data (US AF)
- Accuracy
  - ~1 minute for the time of the manoeuvre
  - ~1 cm/s for the Delta-V
- Limitations: continuous thrust for times longer than 1 orbital period
- Computation time: ~1 min for one satellite over 1 day

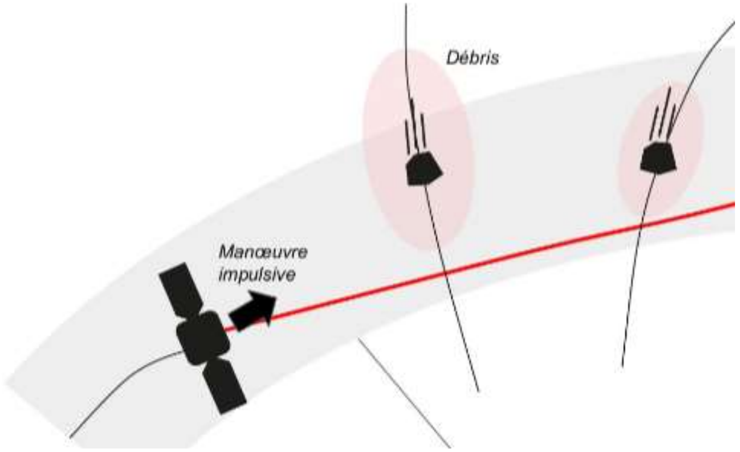
Screening optimisation

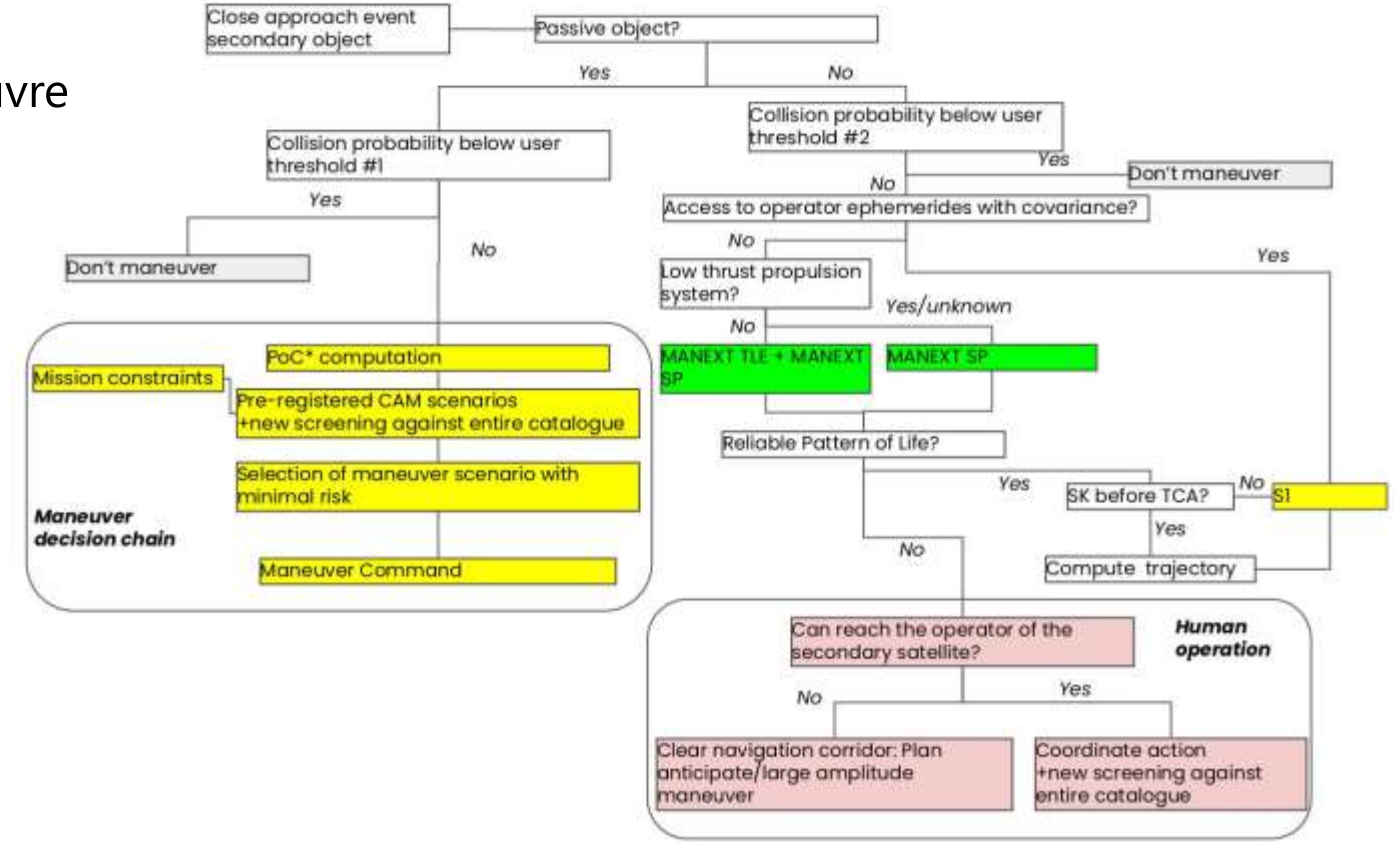
- **Objective**: allow for an estimate of all close approaches between all the objects of the catalogue ("all vs. all")
- Manage memory usage and memory access
  - Cache
  - Systematic binary file conversion
  - RSO grouping to allow efficient multi-threading
- **CATCH method implementation** for faster screening
  - Analytical method with evaluation at the Chebyshev-Gauss-Lobatto nodes
  - Screening time
    - 1 vs 21,000 (worst case): <1 min
    - 21,000 vs 21,000: <2 hours on 4 CPU

Simulator for ground-based automation of the collision avoidance process

Under development

- Pattern of life of satellites taken into account
- Manoeuvre recommendations are established based on reference manoeuvre scenarios
- Probability of Collision (PoC) and re-screening can be fully automated





Autonomous Collision Avoidance with Station Keeping

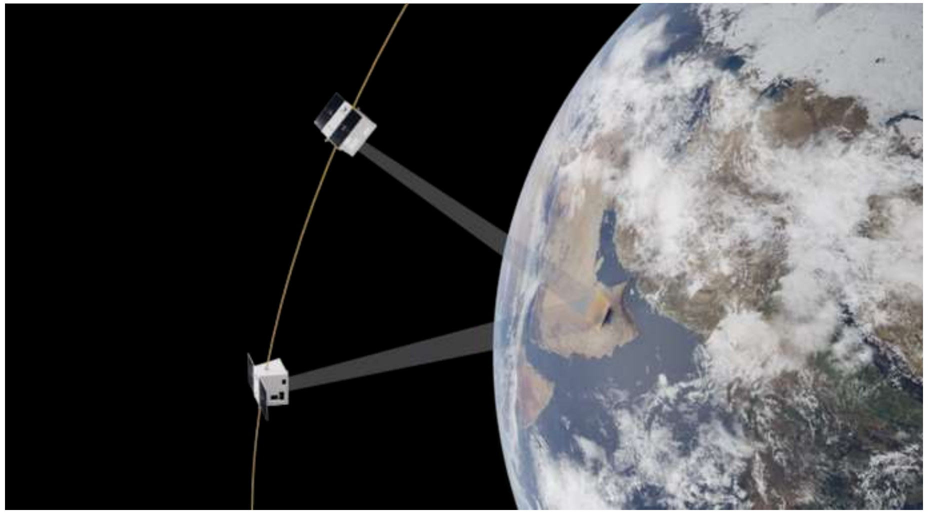
Dr Joris Olympio (Airbus Defence and Space), AOCS & FDS R&D engineer
5 October 2021

AIRBUS

Context

- Earth observation missions need to have fine station keeping for accurately pinpointing Earth observation sites
  - manoeuvres are regularly programmed to **maintain the satellite in a narrow window** around a reference trajectory
  - current and future missions will implement electric propulsion system, with low thrust, for orbit correction

Credits: ESA

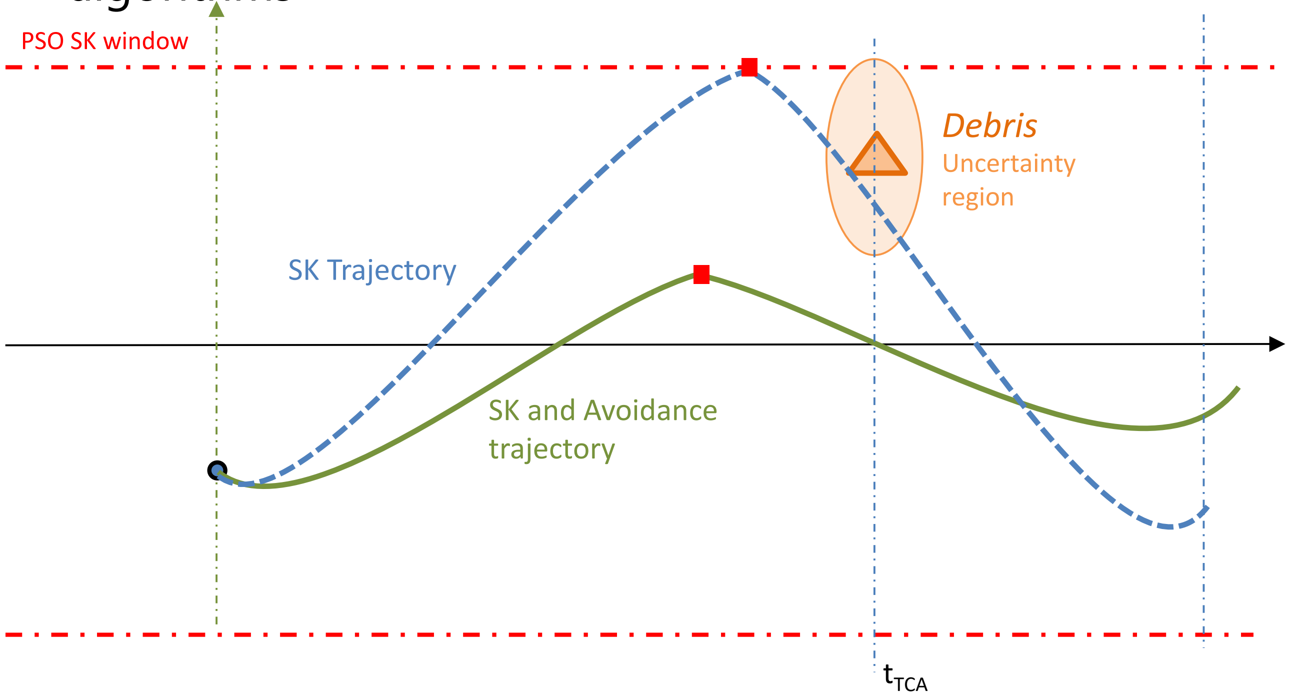


Credits: Airbus

- In the current space environment, filled with debris and active satellites, satellites are subject to conjunction events
- Manoeuvres shall be computed such that the estimated risk of collision (Probability of Collision) falls below a given acceptable risk threshold

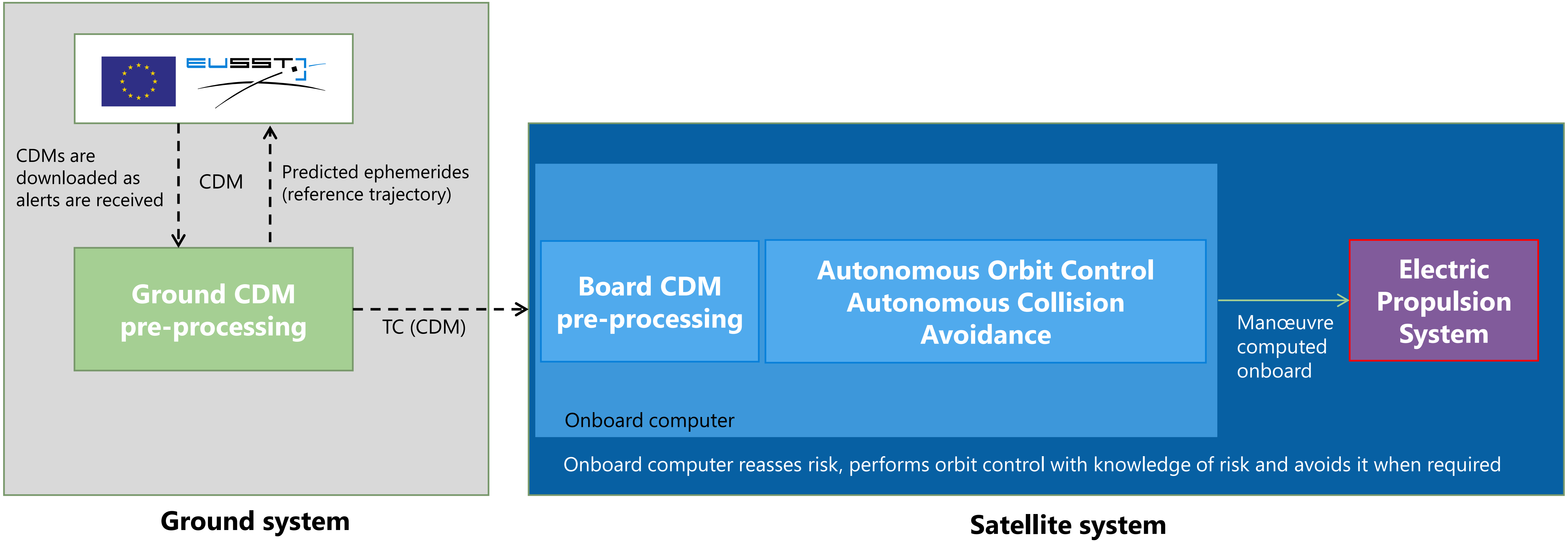
Problematic

- In a nutshell, there are two antagonistic objectives:
  - **keeping the satellite in a narrow window** around a mission reference trajectory
  - **deviating the satellite** away from that reference trajectory when there is a collision risk
- In addition, for critical missions, mission responsiveness requires implementing autonomous algorithms



- Challenges:
  - uncertainty: on position-velocity of secondary object, solar activity and its effect on satellite drag, manoeuvre execution performance
  - manoeuvrability and avoidance strategy of the secondary object
  - multiple risks

Process



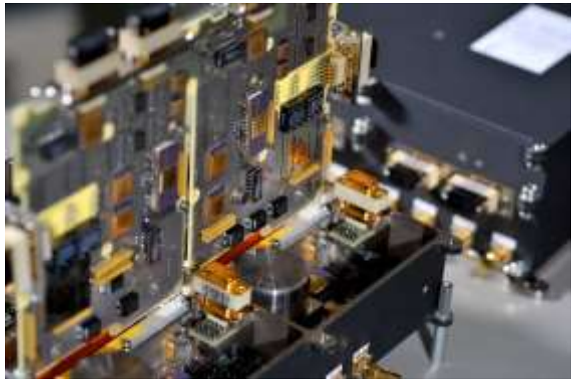
- update CDM with current knowledge of satellite navigation
- filter CDM that are deemed to represent no risk

Main achievements and next steps

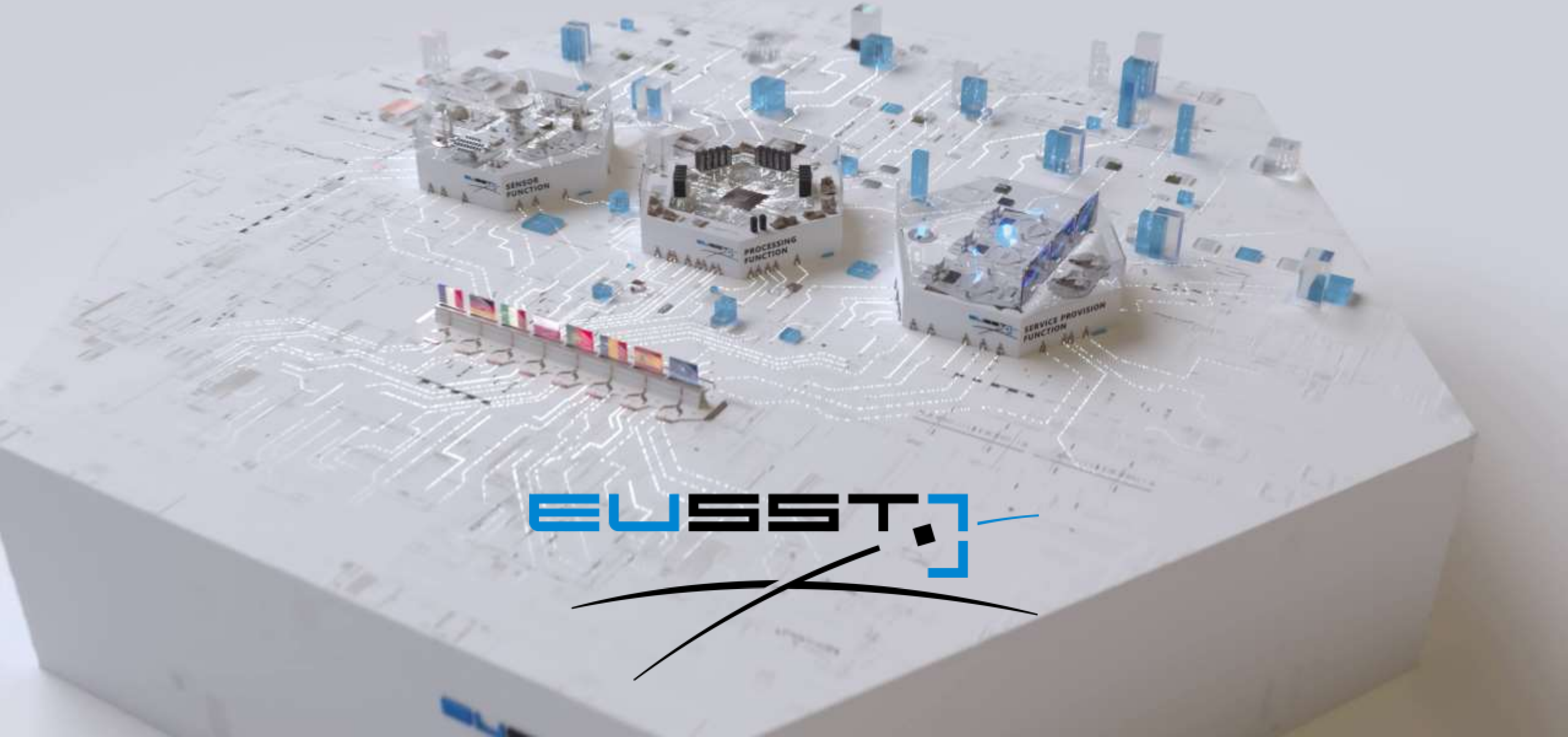
- Achievements
  - Simulator for station keeping with avoidance manoeuvre
  - Robustness campaign done on +2000 conjunction cases and few real cases
  - On-board development for prototyped algorithms is ongoing

- Next steps:
  - Performance estimation on representative avionics
  - Concept of operations and ground-software definition/development

- And later… flight test



Q&A session



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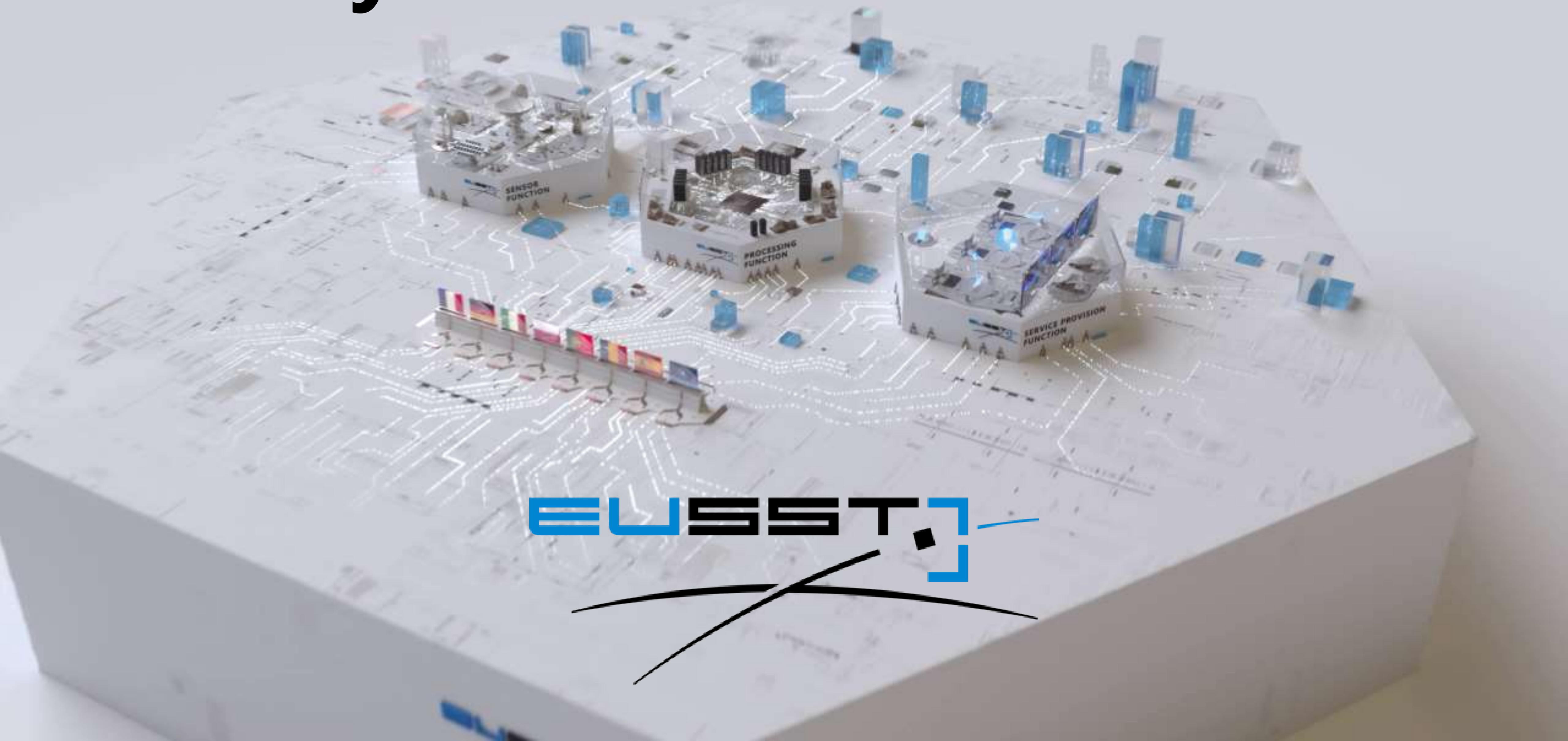
Survey


SENSOR FUNCTION
PROCESSING FUNCTION
SERVICE PROVISION FUNCTION
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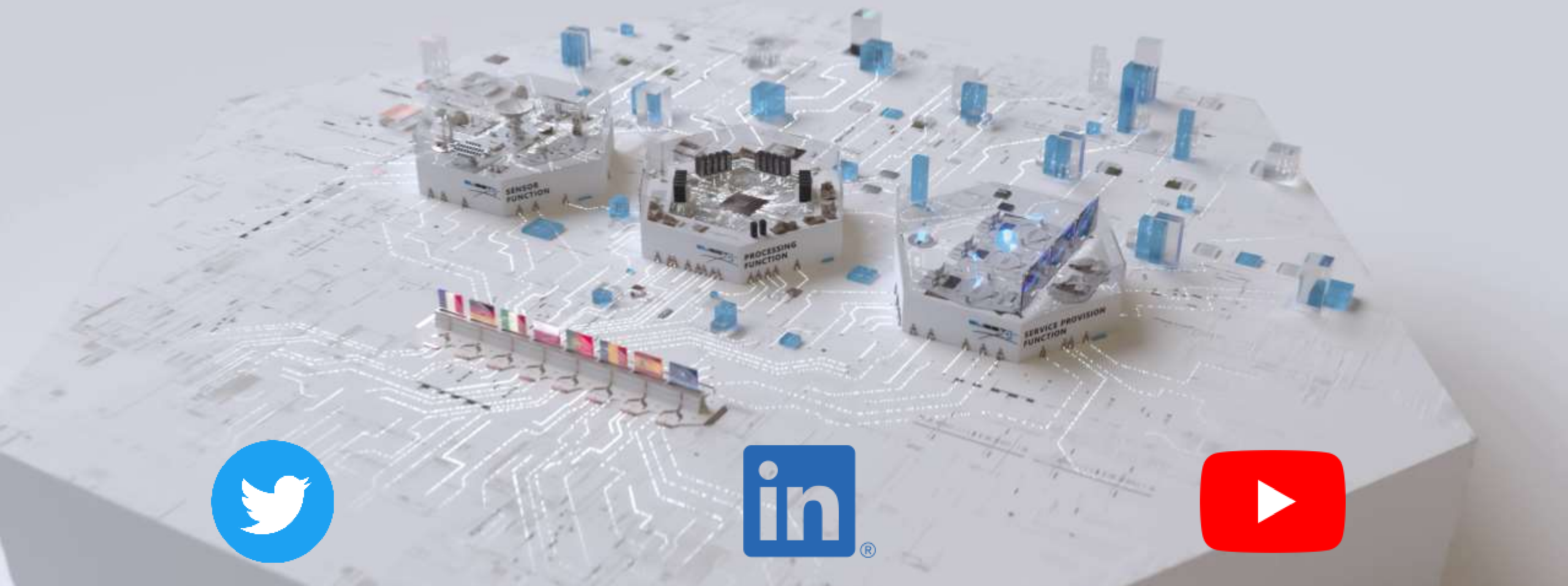
Thank you!



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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 952852, No 785257, No 760459, 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. This message 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.