Welcome and Introduction

User Consultation Platform: Space
Giovanni Lucchi - EUSPA
All EU Space Program components with an integrated market/user driven approach

- Bodies influencing the market
- Navigation Signal Providers
- Chipset, receiver
- Devices
- Content & applications
- Users

Bodies influencing the market:
- Data and services provision
- Storage and processing
- Content & Applications
- Users

Market & User Knowledge:
- Extended Market and technology monitoring and forecasting
- Extended and synergic User Consultation Platform
- Better understanding the MS needs and adding Copernicus Other Users satisfaction survey

Demand Support & users:
- A common market segments approach for all EU space downstream
- Extended key account with main players of the value chain

Offer Creation:
- Creation of new “made in Europe” products and services.
- Large implementation of end-to-end solutions leveraging synergies.
- Supporting entrepreneurship, SME and start-ups

8 parallel sessions

Agriculture and Forestry
Road and Automotive
Rail
Public Transport
Space
SST
Resilient societies
Environmental

EU SPACE WEEK 2023
Welcome to the Space session!

- The User Consultation Platform (UCP) is a forum for users of space data and services to express their needs, share best practices and present case studies.

- Session objective: Collect and adopt user needs and requirements; relevant for: Earth Observation (EO), Global Navigation Satellite System (GNSS), as well as Satellite Telecommunication (SatCom).
Introductory part (30’)

10:00 – 10:15 • Session Agenda presentation; Giovanni Lucchi (EUSPA)

10:15 – 10:30 • EU Space Programme Components current state and future services for users; Ignacio Alcantarilla Medina, Head of Sector Galileo and EGNOS Services and Evolutions, European Commission
Major Applications part I

10:30–11:00 The new standard IoT satellite constellations and the role of the GNSS; Jaume Sanpera (SATELIOT)

11:00–11:30 Using GNSS for orbit determination in the O3b Medium Earth Orbit, Geostationary Orbit and during Electric Orbit Raising; Charles Law (SES)

15’ Break

11:45–12:15 Future Navigation applications for Lunar missions; Samuele Fantinato (Qascom)

12:15–12:45 GNSS for low Earth orbiting satellites: precise orbit determination and radio occultation at EUMETSAT; Pier Luigi Righetti (EUMETSAT)

12:45–13:00 Morning Conclusions

Lunch break
Major Applications part II

14:00–14:15 Cybersecurity Threats in Satellite Systems; Monika Adamczyk (ENISA)

14:15–14:45 GNSS and EO Synergies: a practical approach from GEOSAT; Monica Díez (GEOSAT)

14:45–14:55 Enhanced SST Applications for Space Users through Synergies with GNSS services; Diego Escobar (GMV)

14:55–15:00 Space user needs and requirements conclusions and next steps; Giovanni Lucchi (EUSPA)
We want to hear from you

• Presentations from users will include a summary of GNSS requirements applicable to their particular use case

• After each presentation, we will dedicate a few minutes to:
  – Q&A
  – Open discussion and spontaneous interventions
  – Validation of requirements
EU Space Programme Components
Status and future services for users

User Consultation Platform: Space
Ignacio Alcantarilla Medina, Head of Sector Galileo and EGNOS Services and Evolutions, European Commission
A new EU Space Programme

EU space activities under one umbrella

EGNOS
EGNOS “Makes navigation signals more accurate and trustable for Safety-critical applications”
Operational in 500+ airports & helipads in 32 countries

Galileo
Global satellite navigation and positioning system (GNSS)
More than 3 billion Galileo receivers worldwide

Copernicus
Earth Observation (EO) and monitoring based on satellite & non-space data
Nr.1 world provider of space data and information (>20TB/day)

GOVSATCOM
Secure satellite communications for EU governmental actors
Rapid support over crisis areas

Space Situational Awareness (SSA)
Space Surveillance and Tracking (SST)
Space Weather Events (SWE)
Near-Earth Objects (NEO)

Others
Access to Space
Research & Innovation
Entrepreneurship
Certification & standardisation
Capacity Building
Copernicus
Copernicus components

SPACE

IN SITU

SERVICES

EU SPACE WEEK 2023
Copernicus services

https://atmosphere.copernicus.eu/

https://marine.copernicus.eu/


https://climate.copernicus.eu/


https://emergency.copernicus.eu/
GALILEO and EGNOS
# Galileo and EGNOS Services

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<thead>
<tr>
<th>Galileo Services</th>
<th>EGNOS services</th>
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<tr>
<td>are provided to worldwide users since December 2016</td>
<td>are provided to users since October 2009</td>
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<tr>
<th>Open Service (OS)</th>
<th>Improving GNSS accuracy, intended mainly for high-volume satellite navigation applications for use by consumers</th>
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<tr>
<td>Public Regulated Service (PRS) – Governmental Service</td>
<td>Encrypted service designed for greater robustness and higher availability – secure satellite communication</td>
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<tr>
<td>Search and Rescue Service (SAR)</td>
<td>Locates people in distress and acknowledges that the distress signal has been received</td>
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<td>High Accuracy Service (HAS)</td>
<td>Delivers high accuracy services, freely accessible</td>
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<td><strong>Under preparation</strong></td>
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<tr>
<td>Authentication Service (CAS)</td>
<td>Delivers assisted commercial authentication service (ACAS) for commercial applications</td>
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<tr>
<td>Emergency Service (EWSS)</td>
<td>Warn population at risk</td>
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* OS Navigation Message Authentication (OSNMA) is currently under testing
Galileo Open Service

• Since 2016, anyone with a Galileo-enabled device is able to use its signals providing free of charge outstanding seamless performance worldwide, in terms of ranging, positioning and timing.

Ranging Accuracy, 95% @ AUL - Dual-Frequency - June 2023
Galileo Open Service

- Galileo OS users can benefit from an improved navigation message, since mid-2023, which considerably boosts their performance in terms of robustness and Time To First Fix (TTFF)

- An update of the Galileo Open Service (OS) Service definition Document (SDD) is planned for the end of this year:
  - new MPLs (e.g. Position accuracy at user level, Ranging rate accuracy, Ranging accuracy at high percentiles)
  - improvements of existing MPLs, such as the timeliness of certain Notice Advisory to Galileo Users (NAGU)

- This updated OS SDD will also introduce the Extended Operations Mode, which is characterized by a gradually degrading ranging accuracy with respect to the nominal operational mode, even in case the Galileo Ground Segment is affected by certain issues, thus increasing the robustness of the OS.
Galileo OSNMA

Scope

OSNMA server at GNSS Service Centre (GSC)

Galileo Satellite

OSNMA signal

OSNMA enabled user receiver

CRYPTOGRAPHIC FUNCTION is navigation data authentic?

No

Navigation data not authenticated

Yes

Navigation data authenticated

Trusted use for positioning
OSNMA status and roadmap

- OSNMA SiS ICD (final format) and Receiver Guidelines published in Dec’2022
- Transmission of SiS as per OSNMA SiS ICD (final format) since August 2023
- Operational cryptographic data to be published by end 2023
- Initial Service Declaration (Service Definition Document publication and signal switch to ‘operational’ mode) foreseen by Q1’24
What is the Galileo HAS

• Galileo HAS provides precise corrections for satellite orbit, clock and signal biases

• Galileo HAS corrections distributed via
  – Galileo satellites, E6-B signal (1278.75 MHz)
  – Internet

• Typical accuracy around 20 cm (after convergence), with Precise Point Positioning (PPP) receivers

• (Almost*) global coverage and free

*global coverage of corrections but no global performance commitment yet
HAS – Initial Service Area & Initial Service Performance


HAS Quarterly Performance Reports regularly published at the GSC website (https://www.gsc.europa.eu/electronic-library/performance-reports/galileo-high-accuracy-service-has)
Galileo Search And Rescue

2000: Initial Discussions on SAR and Galileo

2006: Cooperation Agreement on Development

2016: Cooperation on Service Provision: Localisation of Distress Alerts

2020: Agreement on provision of Return Link Service
Galileo SAR: Return Link Service

Emergency Beacon

Distress Location

MEOLUT

COSPAS

SARSAT

ACK

Galileo Ground Segment

Return Link Service Provider

FMCC

ACK

Return Link Message

MCCs

Network
EGNOS services perspectives

Primary means of navigation for Aviation in 2030

• Performance Based Navigation (PBN)
• Better availability (99.9%), more resilience, EU autonomy (with Galileo)
• New Airspace users (helicopters, small aerodromes, drones, …)

Maritime

• Initial service in 2024 for maritime and in-land navigation
• Towards autonomous vessels navigation and zero-emissions shipping
• Not only EGNOS: end to end solutions using HAS/OSNMA and Copernicus

Rail

• Making ERTMS accessible on all lines
• R&I substantial investment to prepare railway operators and signalling industry
• A new service under preparation, facing the challenge of Rail safety standards
Secure Satcom
IRIS²
Infrastructure for Resilience, Interconnectivity and Security by Satellite

Regulation 2023/588 in force since 20 March 2023
Governmental Satellite Communications
Space Surveillance and Tracking (SST)
EUSPA manages and operates the **EU Space Surveillance and Tracking (SST) Front Desk**

- The Agency cooperates with the **SST Partnership** to provide **space safety services**:
  - **Collision Avoidance (CA)**: risk assessment of collision between spacecraft or between spacecraft and space debris
  - **Re-entry Analysis (RE)**: risk assessment of uncontrolled re-entry of artificial space objects into the Earth’s atmosphere
  - **Fragmentation Analysis (FG)**: detection and characterization of in-orbit fragmentations, break-ups or collisions
Space Surveillance and Tracking (SST) Front Desk

- Services and Coordination Platform
  portal.eusst.eu
- Performance Reporting
- SST Helpdesk
  sst.helpdesk@euspa.europa.eu
- SST Taskforce
- User Consultation Platform
  7th Nov 2023 afternoon
- Communication
Executive Summary

The problem

Today satellite IoT is not commercially viable for most use-cases

- Most of today’s market is serviced by GEO, coverage is limited by region and terrain.
- All solutions in the market today (LEO and GEO) use expensive, proprietary devices (often >$100) and operate on closed networks that are satellite-only.
- This makes today’s solutions too expensive to address the vast majority of use cases.

Result:
Current market is only 4m connections

80% of the world has no mobile coverage
A telecoms-focussed standards-based approach

- As a **LEO solution**, Sateliot provides coverage everywhere.
- Having incorporated satellite NB-IoT into **3GPP standards**, devices can **roam from terrestrial telco networks to satellite**.
- Existing, **sub-$5 off-the-shelf devices** can be used, and service can be provided close to a terrestrial price point.

Only 5G NTN NB-IoT can offer coverage everywhere at a terrestrial price point.
**Technology**

**A standards-based approach is the only way to meet customer demands**

There is a huge market opportunity for Satellite IoT if a solution could use off-the-shelf, non-proprietary technology. They evaluated three standards-based protocols against these requirements.

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<tr>
<th>Customer demands…</th>
<th>sigfox</th>
<th>LoRa</th>
<th>3GPP</th>
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<tbody>
<tr>
<td>1. Designed for massive IoT, and affordable</td>
<td>✔️</td>
<td>✔️</td>
<td>❌</td>
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<td>2. Extension of existing MNO coverage</td>
<td>✗</td>
<td>✗</td>
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<td>3. Seamless ability to roam between terrestrial and space infrastructure, with a single device</td>
<td>✗</td>
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<td>4. Single point of contact for billing and service, ideally with existing service provider</td>
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We selected NB-IoT, and then worked for 3 years with the standards organisation to implement satellite connectivity.
Only NB-IoT NTN can offer a price that unlocks the Massive Satellite IoT market.

Superior pricing enabled by roaming store & forward, dramatically reducing upfront CapEx.

- **Massive IoT**
  - Low cost, low energy
  - Small data volumes
  - Massive numbers

- **Critical IoT**
  - Ultra reliable,
  - Very low latency
  - Very high availability

Area size representative of relative of market size.
Competition

A LEO solution is the only way to offer coverage everywhere

GEO

Connection difficulties due to terrain blockage

Specific regional coverage

LEO

Unencumbered

Global coverage

Note: LEO (Low Earth Orbit), GEO (Geostationary orbit)
has reshaped mobile standards, becoming the first 5G NB-IoT telecom operator from space, providing standards-based, low-cost, coverage everywhere, by unique implementation of roaming store & forward technology
Sateliot has been #1 contributor from the space industry to the Release 17

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<tr>
<th>Technology</th>
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<td>Sateliot</td>
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#EUSpace
Sateliot’s approach enables seamless terrestrial extension

- Same device (<$5 OTS)
- Seamless end-user experience (ROAMING)
- Customer keeps 1 point-of-contact for billing/support/etc
- Immaterial price increase vs current contract
- Service provided with fewer satellites using patent pending store & forward technology
- New capex-free revenue stream for the MNO
Sateliot has validated the key technologies End-to-End with Telefonica

Key technologies validated

- Satellite SDR payload
- Software NB-IoT NTN eNodeB & UE
- Store & Forward network functionality
- NB-IoT EPC Core Network deployment in AWS
- 3GPP Standard Roaming interface with MNO
- Network Attach procedure
- Mobile Originated message
Technology

GNSS is part of the solution:

- UEs in IoT-NTN are assumed with GNSS capability
LEO Constellation: Problem Statement

- Satellites pass through at a very high speed (e.g. 7.8 km per second).
- UE can be also mobile

Observation #1: Frequency shifting has to be compensated taking into account Satellite and UE movement.
GNSS is part of the solution

Doppler compensation

In the UL the UE must pre-compensate for the Doppler that the ng-eNB will see. To facilitate this function the instantaneous ephemeris of the serving satellite is transmitted in SIB31 either as a pair of positional and velocity state vectors or as osculating Keplerian parameters. This is consistent with the OPM format recommended by the CCSDS [17].


GNSS is part of the solution

**GNSS requirement for doppler compensation**

The satellite shall provide means to distribute to the payload UTC time, Position and Velocity with frequency of 1 Hz and latency of 0.5-0.75 s with the following accuracies:
- position: < 10 m
- velocity: < 0.03 m/s
- UTC time: < 200 ns.

The UTC time shall be stamped on each position, velocity frame in order to guarantee data usefulness.

The spacecraft shall provide a highly accurate PPS signal (within 0.5 ppm error) which shall be accessible by the payload.
Coverage gaps will appear during the rollout of NTN NB-IoT constellations. Additionally, coverage gaps occur in low density constellations as well as in deployed constellations that e.g., experience satellite outage.

Observation #1: Discontinuous coverage is inherent in NTN NB-IoT and shall be handled to avoid service degradation and extraneous UE power consumption.

Observation #2: To mitigate discontinuous coverage, the UE and network must be aware of gaps in coverage.
GNSS is part of the solution: LEO Low Density Constellation

In a low-density LEO constellation, the service link will only be available for the time the UE is within coverage of one of the satellites.

Three sizes of the satellite visibility cone have been considered to establish the satellite coverage footprint. They correspond to the following elevation angles as seen from a IoT device:

- 45 degrees
- 30 degrees
- 25 degrees
GNSS is part of the solution: Temporal discontinuity in coverage

Challenges related to discontinuous coverage regard differentiating UE behaviour while in- and out of coverage:
1. Coverage prediction.
2. Energy management.

Satellite ephemeris information broadcast by the satellite can be used by IoT devices to predict when the satellite will come again into coverage so that the IoT device can transition to a deep sleep mode during the no-coverage period and wake up again at the time that the satellite is flying by.

**GNSS device positioning**

**SIB32: Coverage prediction** is facilitated by SIB32. In the earth-moving cell scenario prediction is based on SGP4 parameters transmitted in SIB32.
A full constellation with intersatellite link to start providing services is needed
Sateliot store&forward roaming authentication methodology

In t0 the satellite stores the keys

In t1 forward the keys closes the authentication

Our patent pending technology allow us start providing services with a low-density constellation to non-time sensitive applications
Roaming store & forward tech allows Sateliot to begin delivering service with 4 satellites. Competitors using a similar standards-based approach would need to launch 250 upfront.

Sateliot have filed a patent, protecting the implementation of roaming store & forward, using 3GPP standards.

Service the market years ahead of anyone else
Go-to-market with a much lower capex requirement
Become profitable without servicing the NRT market
Market

We are at the blink of a global revolution...

Sources: Company Analysis, Silverpeak Analysis, GSMA, Space News. Market price is the FY’22 Iridium ARPU (Average Revenue Per User); $400m market size assumes 35% Iridium market share.
In Sateliot we are aware of the challenges imposing on our planet today...

and we are fully committed to easing them
Sateliot is supporting NGO with free of charge connectivity
Because a connected world is a better world

www.sateliot.space
Barcelona · San Diego · Space

Jaume Sanpera · jaume@sateliot.com
+1 650 405 7007  +34 647 708 253

SATELIOT
Space · Connecting · 5G IoT
Using GNSS in the O3b MEO Orbit At GEO and during Electric Orbit Raising

User Consultation Platform: Space

Charles Law, SES Director Flight Dynamics
GNSS at GEO, O3b MEO and during EOR

Contents

• Introduction to SES
  – SES Services
  – SES Satellites – Multi-Orbit and mPOWER

• Experience with GNSS
  – Position and Velocity Accuracy: GEO, MEO, electric orbit raising and on station

• Conclusions and Recommendations
  – Conclusions using GNSS from operations
  – Recommendations
Introducing to SES
European Player Leading Satellite and Space Innovation Worldwide

**VIDEO SERVICES**
- Broadcasts over 8,000+ TV channels to >1 billion people
- Delivers HD & Ultra HD content to any platform, on any device
- Reaches 369 million TV households*
- 620+ hours of premium sports & events per day

**DATA SERVICES**
- Supports telcos with networks roll-outs and connecting remote areas
- Delivers high-performance connectivity for Governments*
- Connects over 300 customers in 130 countries on planes, ships, oil rigs
- Helps restore connectivity after natural disasters

#EUSpace
Revolutionising Space with Unique Combination of MEO and GEO

**GEOSTATIONARY EARTH ORBIT (GEO):** Unparalleled reach

- **>45** GEO widebeam
  - Reaching millions of TV households worldwide
  - Providing comprehensive reach to deliver data connectivity

- **4** GEO High-Throughput Satellites (HTS)
  - Improving value proposition for data applications

- **3** More GEO to come

- **20** MEO HTS
  - High throughput, lowest latency

#EUSpace
O3b mPOWER

Industry-Best Throughput
Predictable Performance
Flexible Bandwidth
High Availability
SES’s unique multi-orbit strategy

**GEO**
- 36,000km
- GEO Widebeam or HTS
- Broad coverage—3 satellites
- High latency—operationally simple
- Xenon Ion Low thrust Orbit raising

**MEO**
- ~ 8,000km
- O3b mPOWER
- Extended reach—6 satellites, scalable
- Low latency—operationally simple
- High throughput, high flexibility, high performance
Experience with GNSS
Comparison Accuracy MEO and GEO

Position Accuracy [m] One sigma

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<th>O3b MEO</th>
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<td>Position Accuracy [m] Ones Sigma</td>
<td>Velocity Accuracy [cm/s] One Sigma</td>
<td>Position Accuracy [m] Ones Sigma</td>
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<tr>
<td>On-station</td>
<td>2 m – 3 m</td>
<td>0.1 cm/s</td>
<td>20 m – 40 m in X and Y</td>
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<tr>
<td>Electric Orbit Raising</td>
<td>5 m – 10 m</td>
<td>2.5 cm/s</td>
<td>25 m – 50 m in X, Y and Z</td>
</tr>
<tr>
<td>Dual station tone ranging</td>
<td>N/A</td>
<td>N/A</td>
<td>75 m – 100 m</td>
</tr>
</tbody>
</table>

- GEO accuracy reduced 10x compared to MEO
- Sufficient for orbit determination and maneuver calibration
Using GNSS Conclusions
Simplifying Operations

- Continuous, no active operations required
- Measurement gaps and outliers in GEO
- Reduction in TT&C ground infrastructure costs
- GEO accuracy reduced 10x compared to MEO
- Sufficient for orbit determination and manoeuvre calibration
- Thruster modelling largest source of error
- Resets due to interference
GNSS User Requirements
Enabling the Future

- Higher availability in the Geostationary Orbit
- Direct Antenna upwards to GEO
- Lower Receiver Cost
- Reduction of Interference
Future Navigation Applications for Lunar Missions

User Consultation Platform: Space
Samuele Fantinato, Qascom Srl
Outline

- Main Updates on Lunar Exploration Plans
- Future Applications with need for Positioning, Navigation and Timing
- Commercial Experimentation of GNSS on the Moon: the LuGRE Mission
- The GEYSER product: from LEO to Moon PNT applications
- Conclusions
Main Updates on Lunar Exploration Plans
Main Updates on Lunar Exploration Plans

- Since 2018, the Global Exploration Strategy has renewed the focus on Moon exploration.

- The roadmap foresees, for the current decade, Human and Robotic Lunar surface missions.
  - NASA, after 2022 Artemis test launch, is planning Artemis II in 2024 (crewed mission in cislunar space) and Artemis III as early as 2025 with a crewed mission on the lunar surface.
  - Europe is planning to send the first European on the Moon surface by 2030.
  - Europe is contributing on Lunar Exploration with:
    - Lunar transportation for science, logistics and infrastructure (Landers)
    - Communications and navigation systems (Moonlight)
    - Lunar surface science and Technology Demonstration
    - Operations support for Astronauts (such as medical systems).

- For long-term exploration initiative, the Communication and Navigation capability is crucial!

- Interoperable Lunar PNT architectures under definition are the NASA “Lunar Communications Relay and Navigation Systems” and ESA “Lunar Communications and Navigation Services”
Moon Business Opportunities

- More than 250 commercial and institutional missions are forecast to launch to the Moon between 2022 and 2032, including scientific, robotic, and human crewed missions.

- $137 billion investment by 2032, [NSR]

- Communication and Navigation services will support the development of diverse application areas and innovative business opportunities.

- These are expected to initially focus on:
  - Electricity
  - Constructions & Manufacturing
  - Transport and Logistics
  - Habitation
  - Food & Waste Management
  - Smart Infrastructures

Future Applications with Need for Positioning, Navigation and Timing
The Role of GNSS and Lunar PNT Services

• GNSS Services (Available now!) and Lunar PNT Services (> 2025) will cooperate for the Moon exploration [IOAG].

• These are considered a key part of a broader navigation ecosystem including on-board sensors (IMU, Altimeters and Vision Based Navigation Systems).

[IOAG] Report from Interagency Operations Advisory Group (IOAG) to ICG. 26th Meeting of the ICG Providers’ Forum, 9 October 2022
Overview of Future Applications with Need for Positioning, Navigation and Timing

<table>
<thead>
<tr>
<th>Applications</th>
<th>GNSS</th>
<th>Lunar PNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Technology Demonstrators (CubeSats)</td>
<td>✗</td>
<td>☑</td>
</tr>
<tr>
<td>Lunar Spacecrafts</td>
<td>☑</td>
<td>☑</td>
</tr>
<tr>
<td>Rovers</td>
<td>☑</td>
<td>☑</td>
</tr>
<tr>
<td>Astronauts</td>
<td>☑</td>
<td>☑</td>
</tr>
<tr>
<td>Landers</td>
<td>☑</td>
<td>☑</td>
</tr>
</tbody>
</table>

Image Credit: ESA
Commercial Experimentation of GNSS on the Moon: the LuGRE Mission
LuGRE GNSS Payload Overview

- Qascom is the provider of the GNSS Payload for the **Lunar GNSS Receiver Experiment (LuGRE)**, under a NASA-Italian Space Agency (ASI) initiative in the frame of the **Commercial Lunar Payload Services (CLPS)**

- The Payload will fly and land to the Moon (Mare Crisium 18°N, 62°E) in 2024, on board the **Firefly Blue Ghost Mission 1 (BGM1)**

- The GNSS payload is a Moon customized version of Qascom **QN400-Space SDR receiver** (GPS/GAL, L1/L5).

- The **main challenges** of the Development have been:
  - Maximize GNSS Data Collection according to LuGRE Mission Operational Concept
  - Deliver a Payload matching the schedule of the BGM1 Commercial Mission
  - Improve the Robustness of the Receiver for the Lunar Radiation Environment
  - Upgrade the Receiver High Sensitivity Processing and Positioning for Moon scenarios

- The **GNSS Payload Flight Model** has been successfully delivered to Firefly in 2023
GNSS Data Collection

• The GNSS SDR receiver designed with the capability to operate in:
  – Real Time Processing Mode (Standard GNSS Processing)
  – Sample Capture Mode (IQ Sample Collection)

• Moon Transfer Orbit Experiments
  – LuGRE Antenna is in a stowed configuration
  – Antenna pointing to the Earth is achieved through Lander re-orientation (requires consumption of helium)
  – Experiment of 1hr Max duration
  – Real Time Processing and Sample Capture Modes and a combination of the two
  – Uplink of Aiding Data (Eph) and receiver configuration Data (CFG)
  – Binary Data Downlink via X Band at max 16 Kbps

The LuGRE mission Objectives:
• Receive GNSS signals at the Moon. Return data and characterize the lunar GNSS environment.
• Demonstrate navigation and time estimation using GNSS data collected at the Moon.
• Use collected data to support development of future GNSS receivers
LuGRE Payload Architecture

- The LuGRE payload architecture is composed by the following elements:
  - A **GNSS Receiver (COTS)**, in dual cold redundant configuration managed by a supervisory board
  - A **High Gain L-band antenna** optimized for GNSS L1 and L5 bands (~ 15 dBic gain)
  - A **Front-End Assembly** incorporating an LNA > 40 dB Gain, NF = 1.5 dB
GNSS Receiver HW and SW

• LuGRE GNSS Rx Hardware uses QN400-SPACE hardware, based on COTS EEE. The Rx HW three main modules are:
  – Receiver Module
  – RF Add On Module
  – Receiver Carrier

• The **Supervisory Board (new development)** is intended to provide Radiation Protection and Manage the redundancy

• The receiver **Firmware and Software** upgraded to support moon GNSS scenarios: high sensitivity acquisition and tracking and MTO/Surface Precise Orbit Positioning engine

• GNSS Receiver SW is upgradeable via uplink command
The GEYSER product: from LEO to Moon PNT applications
The GEYSER Project

- GEYSER “GalilEo cYber SpacE Receiver” project is intended as evolution of the ENSPACE project to add the GNSS space receiver with new added value functionalities to realize a close-to-market product (TRL-7). Innovations are in the following directions:
  - New Satellite Markets
  - Emerging GNSS Applications in Space
  - GNSS Receiver Hardware Technology Upgrades
  - GNSS Receiver Processing and Plugin Software Upgrades

- GEYSER (2021-2023) is an EUSPA contract GSA/GRANT/04/2019 "Filling the gaps and emerging E-GNSS receivers technologies”

- Consortium
GEYSER Focus on Space Cybersecurity

• GNSS Receiver are the **primary source** of Position, Velocity and Timing data for the Navigation system of spacecrafts.

• Space GNSS receivers are a **mission-critical element** in most LEO missions, including Mega constellations

• **Jamming, Spoofing and Cyber Threats** likelihood is increasing in Space
  
  – **Jamming**: technology needed to jam satellites is commercially available and relatively inexpensive
  
  – **Space Spoofing** of GNSS receivers is feasible

• **New Space GNSS Receivers** shall embed Cybersecurity and Robust PNT features to increase the reliability of space operations and services
GEYSER Product

- **GEYSER key Evolutions:**
  - New HW Design
    - RF board + Digital board + Supervisory board (Radiation Tolerant)
    - 2x Antennas Inputs
    - 2x Frequency (Configurable)
    - Target lifetime 5-7 y
  - Software composed by a Core Module and GNSS Application plugins:
    - Cybersecurity *(Galileo OSNMA, A/S for Space)*
    - Robust PNT (A/J for Space)
    - High precision Navigation (Dual Frequency POD)
    - High Dynamics Navigation
GEYSER Evolutions for Moon Applications

- Qascom has the ambition to develop future PNT receivers for Moon applications, starting from GEYSER receiver technology.

- GEYSER receiver technology provides the following advantages:
  - QN400-SPACE flight heritage.
  - Recent Successful Environmental qualification for the LuGRE Moon Mission.
  - Software Defined Radio concept
  - Possibility to combine **GNSS and Lunar PNT**.
  - New Space Technology (short time, lower costs)

- The following upgrades are envisaged:
  - **Hardware**: update of the RF Board support to **S-band** (Band of for Lunar PNT)
  - **Software**: FPGA/SW processing of Lunar PNT Services. Update of the Navigation Engine for the Lunar Use cases.
Conclusion
Conclusion

- Hundreds of Commercial and Institutional missions are reaching the moon in the next decade.
- Communication and Navigation planned services by NASA and ESA will be strategic to support exploration and diverse application areas.
- GNSS and Lunar PNT receiver technology shall evolve to these new Space scenarios.
- LuGRE GNSS Receiver represent the first technology demonstrator for GNSS and PNT on the moon.
- The GEYSER product developed, for LEO applications, has the ambition to become a key player for Moon PNT applications.
## Conclusion on Application Requirements

<table>
<thead>
<tr>
<th>Applications</th>
<th>GNSS</th>
<th>GNSS Rx Tech</th>
<th>Lunar PNT</th>
<th>Lunar PNT Rx Tech</th>
</tr>
</thead>
</table>
| Early Technology Demonstrators (CubeSats) | 3D Pos Accuracy < 1 Km  
3D Vel Accuracy < 1 m/s  
Time Accuracy < 50 us | High Gain Antenna ~ 15 dB  
High Acq. Sensitivity < 23 dBHz  
MultiConstellation & MultiFREQ  
Ground Aiding (GNSS Ephemeris)  
Lunar POD GNSS Kalman Filter | 3D Pos Accuracy 100-300m  
3D Vel Accuracy 0.5-1 m/s | Support to S Band  
Lunar PNT Kalman Filter  
Lunar Reference System |
| Lunar Spacecrafts             |                                   |                                               | 3D Pos Accuracy 100-300m  
3D Vel Accuracy 0.5-1 m/s | Support to S Band  
Lunar PNT Kalman Filter  
Lunar Reference System |
| Rovers                       | Navigation Engine using GNSS and External Sensors (IMU, DEM) | Horiz. Pos Accuracy 10-50m  
3D Vel Accuracy 0.1-1 m/s | Navigation Engine Lunar PNT and External Sensors (IMU, Altimeter, DEM) | Support to Lunar Beacon |
| Astronauts                    |                                   |                                               |                                                     |                                             |
| Landers                      |                                   |                                               |                                                     |                                             |
EU SPACE WEEK 2023

www.euspaceweek.eu | #EUSW
GNSS for low Earth orbiting satellites: precise orbit determination and radio occultation at EUMETSAT

User Consultation Platform: Space

Francisco Sancho on behalf of the RO and POD teams, EUMETSAT
Agenda

• What is EUMETSAT?
• Why does EUMETSAT need GNSS data?
• What are the operational needs for GNSS data at EUMETSAT?
• What other needs are there for GNSS data at EUMETSAT?
• Conclusions
What is EUMETSAT?
EUMETSAT

• European Organisation for the Exploitation of Meteorological Satellites.
• An intergovernmental organisation with 30 member states.
• Mission:
  – Establish, maintain and exploit European systems of meteorological satellites.
  – Contribute to the operational monitoring of the climate and the detection of global climatic changes.
Current EUMETSAT satellites

**SENTINEL-3A & -3B (98.7° incl.)**
Low Earth, sun-synchronous orbit
Copernicus satellites delivering marine data services from MWIR altitude

**JASON-3 (63° incl.)**
Low Earth, non-synchronous orbit
Copernicus ocean surface topography mission (shared with CNES, NOAA, NASA and Copernicus)

**Sentinel-6 Michael Freilich (68° incl.)**
Low Earth, non-synchronous orbit
Copernicus ocean surface topography mission (shared with NASA, NOAA, ESA and Copernicus with support from CNES)

**METEOSAT-10, -11**
Geostationary orbit
Meteosat Second Generation
Two-satellite system
Full disk imagery mission (3 mins)
(Meteosat-11 (0°))
Rapid scan service over Europe (3 mins)
(Meteosat-10 (9.5° E))

**METEOSAT-9 (45.5° E)**
Geostationary orbit
Meteosat Second Generation providing Indian Ocean data coverage

**METOP-B & -C (98.7° incl.)**
Low Earth, sun-synchronous orbit
EUMETSAT Polar System (EPS)/Initial Joint Polar System

**MTG-I**
Geostationary orbit
Meteosat Third Generation imaging mission, currently in commissioning phase
Why does EUMETSAT need GNSS data?
GNSS radio occultation (RO)

- Computation of atmospheric profiles (pressure, temperature, humidity) from the bending of the GNSS signals received by a low Earth orbiting (LEO) satellite.

- Requires precise knowledge of:
  - GNSS orbits and clocks.
  - LEO satellite orbit and clock, derived from precise orbit determination (POD) based on GNSS measurements taken by the on-board receiver.

- At EUMETSAT:
  - GNSS orbits and clocks are obtained from external parties.
  - POD is performed in house.

Credit: Lauritsen et al., GRAS SAF project and products, 2008
Altimetry

• Measurement from LEO satellites of mean sea level and its evolution over time.

• Requires precise knowledge of:
  – LEO satellite orbit, derived from precise orbit determination (POD) usually based on GNSS measurements taken by an on-board receiver.

• At EUMETSAT:
  – POD for operational altimetry processing is obtained from external parties.
  – POD is performed in house for monitoring purposes.
## EUMETSAT missions requiring GNSS data

<table>
<thead>
<tr>
<th>Mission / satellite</th>
<th>RO</th>
<th>Altimetry</th>
</tr>
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<tbody>
<tr>
<td>EPS / Metop</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Copernicus Sentinel-3</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>Copernicus Sentinel-6</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
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EUMETSAT missions requiring GNSS data

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![Mission diagram](image)
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* Future missions

Credit: Donlon et al., https://doi.org/10.1016/j.rse.2021.112395
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* Future missions
What are the operational needs for GNSS data?
GNSS data for RO

• Near real time (NRT):
  – Missions and GNSS constellations:
    – Metop: GPS.
    – Commercial RO (future): GPS, Galileo, BeiDou, GLONASS.
  – Source of GNSS orbits and clocks:
    – GPS, Galileo: External service provider.
    – BeiDou: Currently being added to the external service provider.
    – GLONASS: NTRIP streaming over Internet (under assessment), NASA/JPL (to be assessed).
GNSS data for RO

• Near real time (NRT):
  – Stringent requirements on GNSS data:
    – Product delivery frequency: 10 minutes.
    – Latency: < 5 minutes.
    – Accuracy: 1D mean RMS < 2cm, 1-sigma < 0.05ns.
    – Availability: > 99.5%.
  – Possible future changes:
    – Use of Galileo HAS (via NTRIP) for at least part of the necessary GNSS data might be explored in the future as a possible alternative to the procurement of a dedicated external service.
    – Galileo HAS availability and accuracy would have to be assessed. External service would still be needed for BeiDou.
GNSS data for RO

- Non time critical (NTC):
  - Missions and GNSS constellations:
    - Copernicus Sentinel-6: GPS, GLONASS.
  - Source of GNSS orbits and clocks:
    - GPS, GLONASS: NASA/JPL.
  - Similar accuracy requirements as NRT.
GNSS data for altimetry

• Missions:
  – Copernicus Sentinel-3.
  – Copernicus Sentinel-6.

• Near real time (NRT), short time critical (STC) and non time critical (NTC) processing.

• No need of GNSS data at EUMETSAT: POD based on GNSS (GPS and Galileo) and DORIS is performed by external parties (with their own providers of GNSS data):
  – NRT: Copernicus POD service, procured by ESA/ESRIN.
  – STC, NTC: CNES.

• POD requirements: radial RMS < 10cm (NRT), < 4cm (STC), < 3cm (NTC)
What other needs are there for GNSS data?
GNSS data for RO

- Near real time (NRT):
  - Missions and GNSS constellations:
    - Sentinel-6: GPS, GLONASS.
    - Commercial RO (to become operational in the future): GPS, Galileo, BeiDou, GLONASS.
  - Source of GNSS orbits and clocks:
    - GPS, Galileo: External service provider.
    - BeiDou: NTRIP (under assessment), currently being added to the external service provider.
    - GLONASS: NTRIP (under assessment), NASA/JPL (to be assessed).
GNSS data for RO

• Short time critical (STC):
  – Missions and GNSS constellations:
    – Metop: GPS.
    – Sentinel-6: GPS, GLONASS.
  – Source of GNSS orbits and clocks:
    – GPS, Galileo, BeiDou: External service provider, IGS.
    – GLONASS: IGS.
GNSS data for RO

• Reprocessing:
  – Consistency of climate data records with most up-to-date version of the RO processor.
  – Missions and GNSS constellations:
    – EUMETSAT and third-party RO missions: GPS, Galileo, BeiDou, GLONASS.
  – Source of GNSS orbits and clocks:
    – GPS, Galileo, BeiDou: External service provider, IGS.
    – GLONASS: IGS.
GNSS data for additional POD

- All timeliness regimes (NRT, STC, NTC):
  - Missions and GNSS constellations:
    - Sentinel-3: GPS (and Galileo in the future).
    - Sentinel-6: GPS, Galileo.
  - Source of NRT GNSS orbits and clocks:
    - GPS, Galileo: External service provider.
  - Source of STC, NTC GNSS orbits and clocks:
    - GPS, Galileo: External service provider, IGS.
GNSS data for other purposes

• Ionosphere and plasmasphere monitoring, electron density and electron content above the satellite, making use of GNSS measurements from the on-board receivers.

• Future: Ground station total column water vapour, derived from GNSS measurements, e.g. for validation of satellite water vapour products.

• Future: Procurement of service providing ionospheric electron content maps below the spacecraft altitude, for correction of Faraday rotation effects on scatterometer measurements. This service will rely on GNSS measurements for deriving those maps.

• Future: GNSS reflectometry (GNSS-R), measurement of GNSS signals reflected by Earth, which can be used for altimetry, oceanography (wave height and wave speed), cryosphere monitoring, soil moisture monitoring...
Conclusions
Conclusions

• EUMETSAT does an extensive use of GNSS data, both in NRT and with less demanding timeliness, but with stringent accuracy requirements in most of the cases.

• Galileo HAS (via NTRIP) might be explored in the future as a possible alternative to external service provider of GPS and Galileo orbits and clocks for operational NRT RO processing:
  – Increased accuracy in Galileo HAS orbit and clock corrections would be needed.
  – Addition of GLONASS and BeiDou to Galileo HAS would make it more attractive to EUMETSAT.

• Operational NRT POD for Copernicus altimetry missions, operated by EUMETSAT on behalf of the European Commission, is currently provided by a service procured by ESA.
  – Might make sense for EUSPA to provide in the future a POD service for the EC Copernicus missions.
CYBERSECURITY THREATS IN SATELLITE SYSTEMS

Monika Adamczyk
Cybersecurity Expert
monika.adamczyk@enisa.europa.eu

07 | 11 | 2023
AGENDA

• About ENISA
• Malicious and non-malicious threats
• Associated risks
• Satellite cyber incidents
• Space cybersecurity standards and good practices
• Conclusions
Our mission is to achieve a high common level of cybersecurity across the Union in cooperation with the wider community.
AREAS OF WORK

Cloud and Big Data
COVID19
Critical Infrastructures and Services
CSIRT Services
CSIRTs and communities
CSIRTs in Europe
Cyber Crisis Management
Cyber Exercises
Cybersecurity Education
Data Protection
National Cybersecurity Strategies
NIS Directive
Standards and Certification
Threat and Risk Management
Cyber Crisis Management
IoT and Smart Infrastructures
Trust Services
Trainings for Cybersecurity Specialists
### SATELLITE ELECTRONIC COMMUNICATIONS SERVICES

<table>
<thead>
<tr>
<th>Application</th>
<th>Example of implementation</th>
<th>Economy Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOT (Internet of Things)</td>
<td>Location tracking of a container and alerting in case of anomaly (e.g., door opening)</td>
<td>Transport / Rail</td>
</tr>
<tr>
<td>Network interconnection</td>
<td>Backup trans-national network for the monitoring of European power grids</td>
<td>Energy / Electricity</td>
</tr>
<tr>
<td>Telephony</td>
<td>Satellite-enabled telephony for assessment teams during a disaster with potential destruction/saturation of the terrestrial cell phone networks</td>
<td>Public administration</td>
</tr>
<tr>
<td>M2M (Machine-to-machine)</td>
<td>Monitoring and remote operation of hydroelectric plants in remote areas</td>
<td>Energy / Electricity</td>
</tr>
<tr>
<td>Internet access</td>
<td>Backup of terrestrial-based Internet access for the logistics department of an hospital</td>
<td>Health / healthcare providers</td>
</tr>
</tbody>
</table>
SATELLITE CONSTELLATION INFRASTRUCTURE

SPACE SEGMENT

GROUND SEGMENT

TT&C stations (several of them)
Satellite control centre
Network operation centre

CONTROL SEGMENT

USER SEGMENT

Earth station (Hub/gateway)
Fixed terminals (many of them)
Mobile terminals (many of them)

Internet
Management network
THREATS AGAINST SATELLITES

Non-malicious threats

- Collisions with other bodies
- Mis-computed manoeuvre
- Platform mis-configuration
- Launcher failures
- Non-compliance to radio regulations
- Payload mis-configured

Malicious threats

- Network traffic sniffing
- Phishing
- Signal jamming
- Platform hijacking
- Sabotage
- Software / hardware Backdoor
- Supply chain

Space specific

IT, networks, users
ASSOCIATED RISKS

Technical Risks

Degradation/outage of commercial services
Hijacking of communication capabilities
Information theft, forgery
Damage or destruction of assets in space / on ground

Financial and Commercial Risks

Harm to the company reputation
Loss/degradation of competitive advantage
Loss of commercial capabilities
Financial loss because of penalties
SATELLITE CYBER INCIDENTS

2014
Privilege escalation in the satellite terminal

2015
Satellite signal and information spoofing

2015
Satellite signal and information eavesdropping

2022
Denial of communications service by means of signal jamming

2022
Denial of communications service through exploit in API of ground software

2022
Privilege escalation in satellite terminal by hardware mod

2022
Denial of communications service through privilege escalation in ground software

2023
Privilege escalation in the spacecraft using rogue telecommands

Proof of concept, no actual attack
The rate of publication is increasing.

The chronology of publications shows a bottom-up approach (from technology to methodology).
CONCLUSIONS

• Satellites are **complex and costly systems that provide global publicly available electronic communications services**, often used in critical services

• They are **often used as dual-use systems**, either by design or de facto

• Most **known attacks** on satellite systems **aim to disrupt or deny access to the communications service**

• Satellite systems are exposed to both **“standard” terrestrial and space dedicated threats** (specifics of satellite systems engineering, communications and operations)

• Some of satellite system elements are **located thousands kilometres away from Earth** but this does not mitigate their exposure to cyber-attacks
THANK YOU FOR YOUR ATTENTION
GNSS and EO Synergies: a practical approach from GEOSAT

User Consultation Platform: Space

Mónica Díez
GEOSAT: European EO provider

Provider of Earth Observation (EO) products and services tailored to customer needs, customization of the portfolio to provide images, information and integration with customer operations

European Earth Observation Established Data Supplier of Optical VHR (40 – 75cm) and HR (20m) imagery
Value proposition from GEOSAT

• Quick response to emergencies:
  – 24/7 support.
  – Delivery down to 30 min after acquisition.
  – Global ground segment network.

• Cost-effective and tailored services:
  – Agile company structure. SW/ML dev team for customized solutions.
  – Resolutions down to 40cm, combined with high-precision geolocation.
GNSS in GEOSAT missions

• GEOSAT-1 (2009) 1x GPS Receiver (SGR-07)
  - 12 C/A channels, 1 antenna
  - Mass ~500 g, Power ~1.6W@28V
  - Orbit definition supported by TLEs

• GEOSAT-2 (2014) 2x GPS Receiver (GP2021)
  - 12 C/A channels, 3 antennas
  - Mass ~380 g each, Power 5W@5V, 1.2W@12V
  - Accuracy Position 30m, Timing < 1msec

Credit: SSTL
GNSS in GEOSAT missions

GPS analysis performed from Telemetry

Number of tracked Satellites, Position RMS
GNSS in GEOSAT missions

GDOP : Geometric dilution of precision
GNSS Impact on EO products

• GNSS service is crucial for any EO products
  – Orbit monitoring: definition of orbital parameters
  – Manoeuvres characterization in collision avoidance events
  – Timing and position info, for better processing and geolocation accuracy

• Need for complementary attitude determination from GNSS
  – Star-trackers may not reliable enough
  – Power effective procedure to provide additional information
Change detection products

• Improved GNSS service could help to:
  – Better processing and geolocation accuracy
  – No basemaps or references needed
  – Early warning with automatic change detection

• Requirements
  – Worldwide coverage needed (60°N – 60°S)
  – Service availability >99%
Change detection products

GEOSAT-2 @ Estambul International Airport
Maritime surveillance products

GEOSAT-2 @ Cargo vessels near Cape Town
GNSS requirements from Optical VHR data

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precise Orbit Accuracy (GDOP)</td>
<td>~0.75m (3σ)</td>
</tr>
<tr>
<td>Precise Orbit Velocity</td>
<td>1 – 10 mm/s (RMSE)</td>
</tr>
<tr>
<td>Attitude Accuracy (3D)</td>
<td>0.1º (3σ) per axis</td>
</tr>
<tr>
<td>Timing Accuracy</td>
<td>&lt;75 ns</td>
</tr>
</tbody>
</table>

Final goals are to obtain positioning / time with:

- Lower cost
- Lower weight & dimensions
- Less power consumption
New Space Portugal 2025

- **DATA CENTER**
  - Secure
  - Cloud frontend
  - +6PB

- **ANTENNA**
  - Multipass
  - Triband
  - Polar

- **SPACE SEGMENT**
  - VHR Optical
  - Intraday revisit
  - VNIR + Spectral

- **GROUND SEGMENT**
  - Designed from OPS experience
  - MultiMission Control Suite
  - AI-based Tailored Processing

GNSS support with new requirements would impact on the overall system performance.
Thanks for your attention!
Any questions?
monica.diez@geosat.space
Enhanced SST Applications for Space Users through Synergies with GNSS services

User Consultation Platform: Space

Diego Escobar, Technical Director of SST and STM at GMV
Intro

• Bridging Space users of GNSS to SST
• Focus on synergies between SST and GNSS targeting how GNSS can help in SST for Collision Avoidance applications:
  – Autonomous Collision Avoidance (*use case already in operations*)
  – Late Collision Avoidance Manoeuvre command (*use case under evaluation*)
  – Space corridors for Space Traffic Management (*use case under evaluation*)
  – Trajectory broadcasting using on-board GNSS receivers (*use case under evaluation*)
Autonomous Collision Avoidance

- Current technological trend going towards **autonomy** of satellites, including also Collision Avoidance Manoeuvres (CAMs)
- Use of **on-board GNSS receivers** in combination with collision info from ground allows spacecraft to take **CAM decisions** based on most updated PNT solution available on-board
- **Current example**: Starlink constellation, whose satellites perform CAM autonomously, based on CDMs (Conjunction Data Message) data sent from ground
Late Collision Avoidance Manoeuvre command

• **Time is of essence** when considering decisions about collision avoidance manoeuvres (CAMs)

• Delaying such CAM **decisions** allows reducing the uncertainty of collisions, thus avoiding unnecessary CAMs

• Using **Galileo as a relay system** to transmit a message with the CAM info/trigger helps in reducing considerably the time to communicate with the satellite from ground, allowing much later decisions

• **Next steps**: detail message structure for the Galileo signal, extend on-board GNSS receivers, and define procedure for transmission
Space corridors for Space Traffic Management

- Collision avoidance operations are driven by the uncertainty in the trajectory of objects, which reduces as the possible collision event gets closer in time.

- Using on-board GNSS receivers in closed-loop with the propulsion subsystem of the satellites allows keeping it inside a previously agreed space corridor, considerably reducing uncertainty.

- The size of the space corridor depends on actual capabilities of the propulsion subsystem and allocated propellant budget.

- **Next steps:** feasibility study to assess guaranteed size of space corridor.

(Use case under evaluation)
Trajectory broadcasting using on-board GNSS receivers

- **Current practices** include already on-board collision risk estimation and collision avoidance manoeuvre decision and design
- Next process to move on-board is **conjunction detection**, to identify possible collisions based on information obtained by the satellite itself
- **Broadcasting** of PNT solution from on-board GNSS receiver and **reception** by other satellites, to allow identification of close encounters in the very near future
- **Next step**: technological study to assess required sensors and processing power on-board

(Use case under evaluation)
Thanks
D. Escobar
descobar@gmv.com
Requirement Tables

User Consultation Platform: Space
Víctor Álvarez (FDC) and Giovanni Lucchi (EUSPA)
The new standard IoT satellite constellations and the role of the GNSS

User Consultation Platform: Space
Jaume Sanpera - Sateliot
## LEO Telecom mega constellations – GNSS requirements

<table>
<thead>
<tr>
<th>GNSS user requirements for LEO Telecom mega constellations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position Accuracy</td>
</tr>
<tr>
<td>Velocity</td>
</tr>
<tr>
<td>Timing Accuracy</td>
</tr>
<tr>
<td>Latency</td>
</tr>
<tr>
<td>Position Output</td>
</tr>
<tr>
<td>Access to UTC</td>
</tr>
<tr>
<td>Pulse-Per-Second</td>
</tr>
</tbody>
</table>
Using GNSS for orbit determination in the O3b Medium Earth Orbit, Geostationary Orbit and during Electric Orbit Raising

User Consultation Platform: Space

Charles Law - SES
## MEO & GEO Telecom – GNSS requirements

### GNSS for MEO telecom satellites

<table>
<thead>
<tr>
<th></th>
<th>UCP 2023 reported performances</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Position Accuracy</strong></td>
<td></td>
</tr>
<tr>
<td>On-station</td>
<td>2-3 m 1σ</td>
</tr>
<tr>
<td>Electric Orbit Rising</td>
<td>5-10 m 1σ</td>
</tr>
<tr>
<td><strong>Velocity Accuracy</strong></td>
<td></td>
</tr>
<tr>
<td>On-station</td>
<td>0,1 cm/s 1σ</td>
</tr>
<tr>
<td>Electric Orbit Rising</td>
<td>2,5 cm/s 1σ</td>
</tr>
</tbody>
</table>

### GNSS for GEO telecom satellites

<table>
<thead>
<tr>
<th></th>
<th>UCP 2023 reported performances</th>
<th>UCP 2020 requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Position Accuracy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On-station</td>
<td>20-40 m in X and Y</td>
<td>30 m 3σ</td>
</tr>
<tr>
<td></td>
<td>5 m in Z</td>
<td>18 m 95%</td>
</tr>
<tr>
<td>Electric Orbit Rising</td>
<td>25-50 m in X, Y and Z</td>
<td>150-600 3σ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>180 m 95%</td>
</tr>
<tr>
<td><strong>Velocity Accuracy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On-station</td>
<td>0,05 cm/s 1σ</td>
<td>1 cm/s RMS</td>
</tr>
<tr>
<td>Electric Orbit Rising</td>
<td>2,0 cm/s 1σ</td>
<td>N/A</td>
</tr>
</tbody>
</table>
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BREAK

Back at 11:45
Future Navigation applications for Lunar missions

User Consultation Platform: Space
Samuele Fantinato - Qascom
Lunar Applications – GNSS requirements

<table>
<thead>
<tr>
<th>GNSS for Lunar Applications</th>
<th>Early Technology Demonstrators (CubeSats)</th>
<th>Lunar Spacecraft</th>
<th>Rovers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position Accuracy (3D)</td>
<td>&lt; 1 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity Accuracy (3D)</td>
<td>&lt; 1 m/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Accuracy</td>
<td>&lt; 50 μs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lunar PNT for Lunar Applications</th>
<th>Lunar Spacecraft</th>
<th>Rovers</th>
<th>Astronauts</th>
<th>Landers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position Accuracy</td>
<td>100 - 300 m (3D)</td>
<td>10 – 50 m (Hor)</td>
<td>30 - 100 m (Hor)</td>
<td></td>
</tr>
<tr>
<td>Velocity Accuracy</td>
<td>0.5 – 1 m/s (3D)</td>
<td>0.1 – 1 m/s (3D)</td>
<td>0.5 – 1 m/s</td>
<td></td>
</tr>
</tbody>
</table>
GNSS for low Earth orbiting satellites: precise orbit determination and radio occultation at EUMETSAT

User Consultation Platform: Space

Francisco Sancho - EUMETSAT
## LEO Radio Occultation – GNSS requirements

<table>
<thead>
<tr>
<th>GNSS for Radio Occultation</th>
<th>UCP 2023 requirements</th>
<th>UCP 2020 requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEO POD accuracy in support of RO</td>
<td>&lt;2 cm 1D, RMS</td>
<td>40 cm 95 % sphere</td>
</tr>
<tr>
<td>GNSS Orbit Accuracy</td>
<td>&lt;0.05 ns 1σ</td>
<td>n/a -</td>
</tr>
<tr>
<td>GNSS Clocks Accuracy</td>
<td>&gt;99.5 % -</td>
<td>n/a -</td>
</tr>
<tr>
<td>Availability of service</td>
<td>&lt;5 minutes -</td>
<td>n/a -</td>
</tr>
</tbody>
</table>
Morning session closure with conclusions

User Consultation Platform: Space

Giovanni Lucchi - EUSPA
User Consultation Platform: SPACE

Lunch BREAK
Back at 14:00
GNSS and EO Synergies: a practical approach from GEOSAT

User Consultation Platform: Space

Monica Diez - GEOSAT
# LEO Optical sub metric imagery – GNSS requirements

<table>
<thead>
<tr>
<th>GNSS for LEO Optical Sub metric imagery</th>
<th>UCP 2023 requirements</th>
<th>UCP 2020 requirements ‘POD LEO’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position Accuracy (3D)</td>
<td>0.75 m 3σ</td>
<td>3.5 m 3σ</td>
</tr>
<tr>
<td></td>
<td>0.6 m 95% sphere</td>
<td></td>
</tr>
<tr>
<td>Velocity Accuracy</td>
<td>1-10 mm/s RMS</td>
<td>1-10 mm/s RMS</td>
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<tr>
<td>Attitude Accuracy</td>
<td>0.1° (per axis) 3σ</td>
<td>n/a</td>
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<td>&lt;75 ns -</td>
<td>50 - 100 ns RMS</td>
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</table>
Enhanced SST Applications for Space Users through Synergies with GNSS services

User Consultation Platform: Space

Diego Escobar - Technical Director of SST and STM at GMV
See you in 2025!