Ingegneria delle Telecomunicazioni

Satellite Communications

16. Introduction to Global Navigation Satellite Systems (GNSS)

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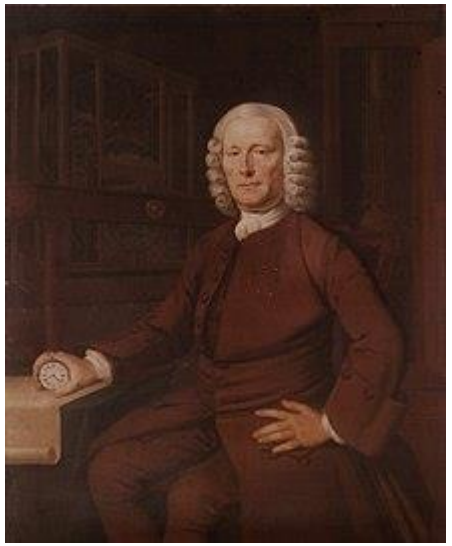
An Old Dream: PNT

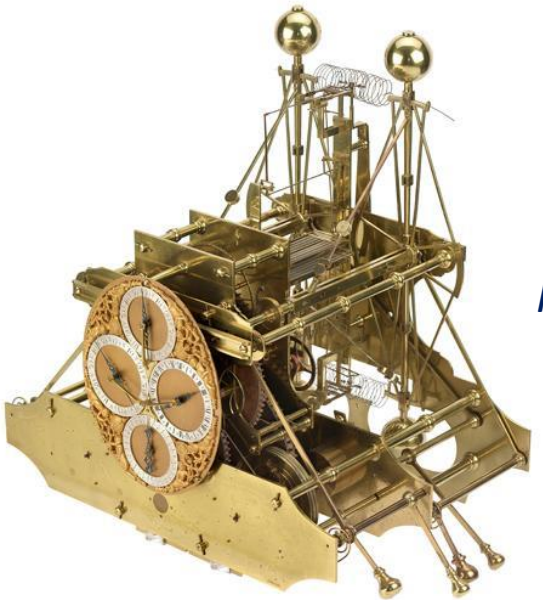
- **Positioning**, the ability to accurately and precisely determine one's location and orientation two-dimensionally (or three-dimensionally when required) referenced to a standard geodetic system (such as World Geodetic System 1984, or WGS84);

- **Navigation**, the ability to determine current and desired position (relative or absolute) and apply corrections to course, orientation, and speed to attain a desired position anywhere around the world, from sub-surface to surface and from surface to space;

- **Timing**, the ability to acquire and maintain accurate and precise time from a standard (Coordinated Universal Time, or UTC), anywhere in the world and within user-defined timeliness parameters.

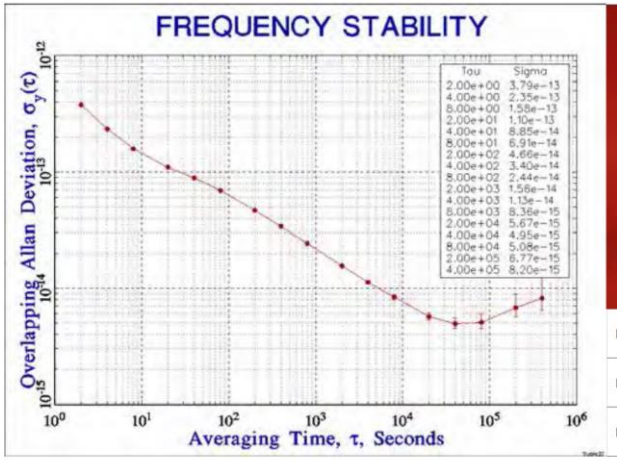
Clock evolution (AD 1735-2018)

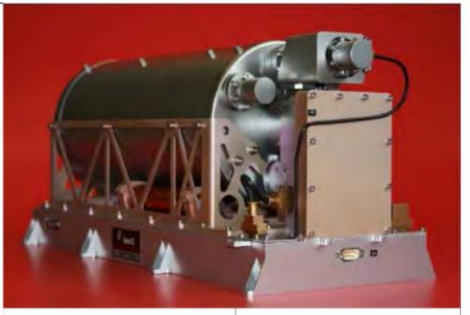




Harrison's clock (AD 1735)
34 kg, duration 24 hours

Mini Passive Hydrogen Maser
Atomic clock - Orolia – CH (AD 2018)
8 kg, lifetime > 10 years in space





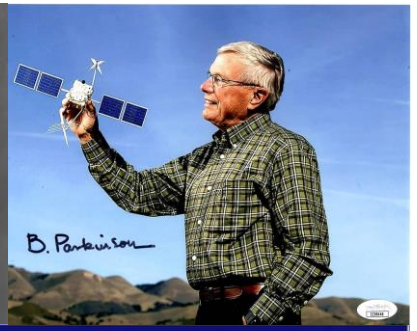
Dimensions	179 x 465 x 175mm
Mass	8Kg
Frequency Drift (/Day)	≤ $1*10^{-15}$ /day

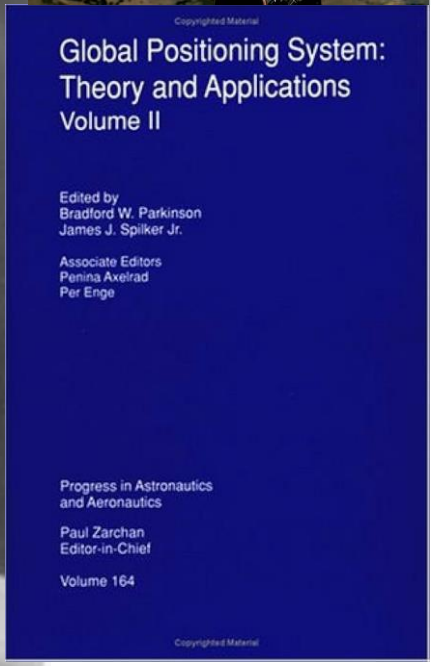
La Guerra Fredda

GPS background

- Cold war stimulated the need for accurate navigation of intercontinental ballistic missiles
- GPS predecessor was MOSAIC (MObile System for Accurate ICBM Control) that was essentially a 3-D LORAN
- A follow-on study, Project 57, was performed in 1963 and it was "in this study that the GPS concept was born“
- That same year, the concept was pursued as Project 621B, which had "many of the attributes that you now see in GPS
- In 1964, the US Army orbited its first Sequential Collation of Range (SECOR) satellite used for geodetic surveying
- The Naval Research Laboratory (NRL) continued making advances with their Timation (Time Navigation) satellites, first launched in 1967 – first atomic clock
- Transit system was also upgraded but not good enough for ICBM applications
- GPS was the result of these studies and pre-developments

Roger Easton, Ivan Getting, Bradford Parkinson





GPS Milestones

- **1963:** A study is completed by the Aerospace Corporation for the U.S. Military. This proposed the idea for satellites with atomic clocks to send continuous signals to receivers to locate moving vehicles on earth and in the air.
- **1974:** Testing begins on the Military-created GPS system NAVSTAR. The proposed NAVSTAR system included 24 satellites.
- **1978-1985:** Testing continued on the NAVSTAR system. During this period, the system begins to be referred to as simply “The GPS System.” By this point, atomic clocks had been added to help provide more precise measurements.
- **1983:** In response to Russia shooting down a plane, President Ronald Reagan offers GPS services to all commercial aircraft once the system is completed. This was offered to enhance safety.
- **1989:** The first fully-operational GPS satellite is launched into space by the U.S. Air Force.
- **1989:** Hand-held navigation devices appear in the US market. Magellan NAV 1000 is thought to be the first.
- **1993:** GPS is operational - **1995:** The last of 27 satellites is launched.
- **2000:** The U.S government discontinued its use of Selective Availability to make GPS more responsive to civil and commercial users worldwide

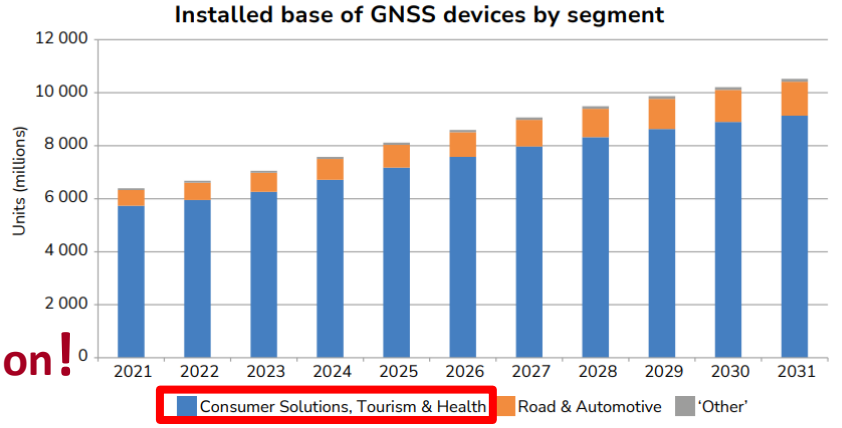
The explosion of GNSS market

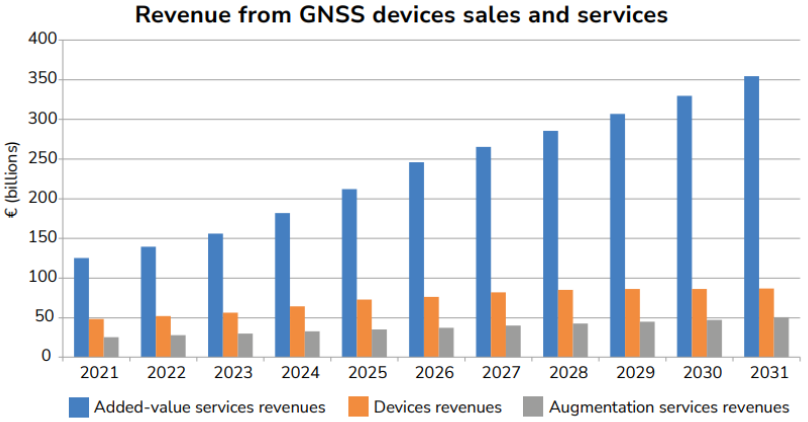
The vast majority are associated with the Consumer Solutions, Tourism and Health segment which contributes roughly 92% of all global annual shipments.

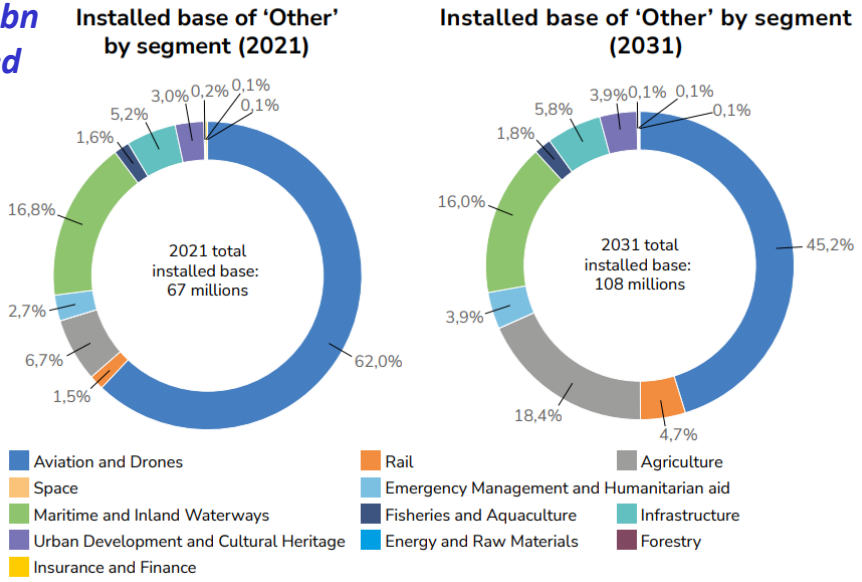
From a regional point of view, it is clear that Asia-Pacific will continue its reign as the largest market. The overall installed base (graph upper-right) will grow from 6.5 bn units in 2021 to 10.6 bn units in 2031

GNSS is the largest satellite worldwide application!

The global GNSS downstream market revenues from both devices and services will grow from €199 bn in 2021 to €492 bn in 2031 with a CAGR of 9.2%. This growth is mainly generated through the revenues from added-value services

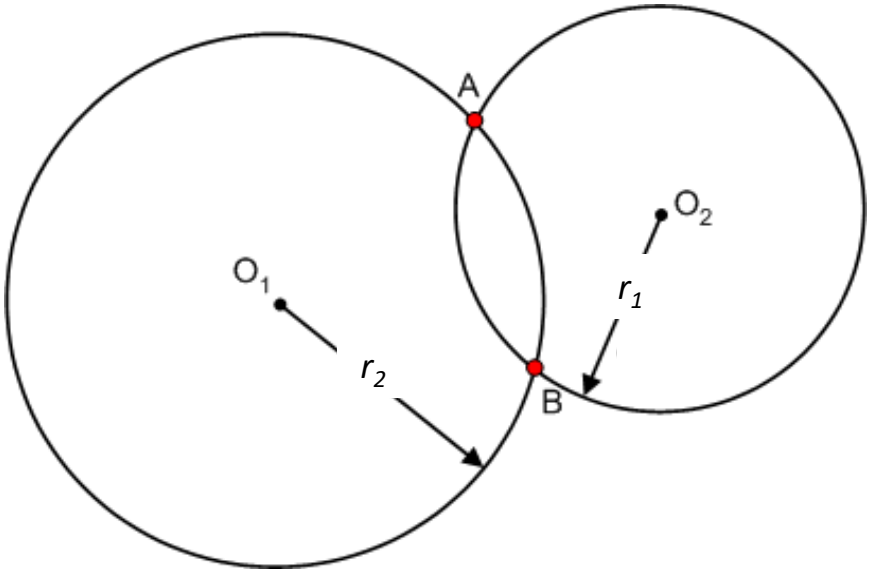






Main Problem: 2D Positioning from range measurements

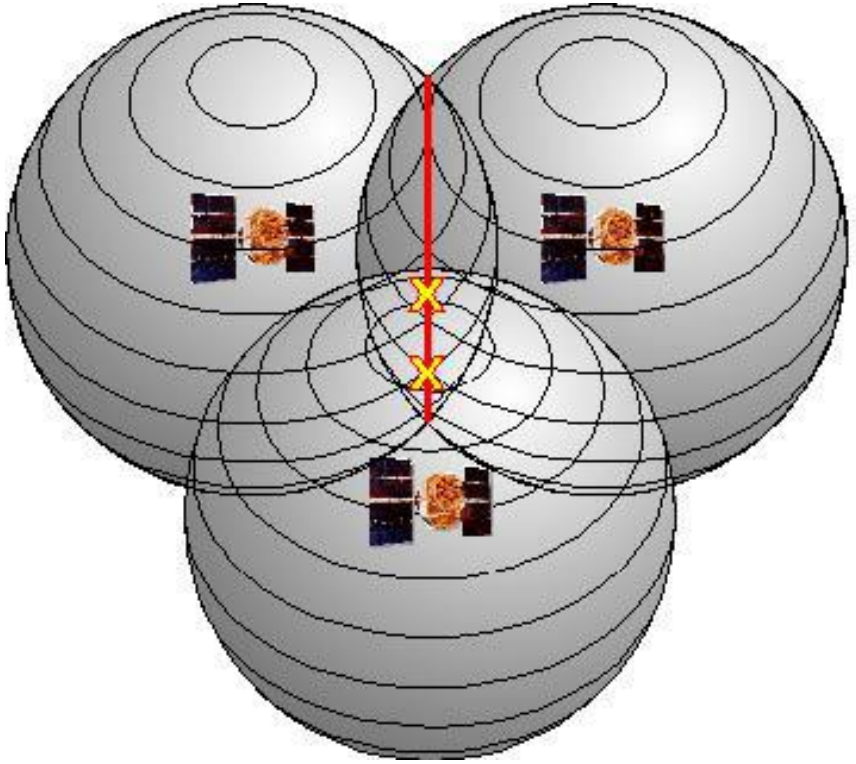
*"The position of a certain point in space can be found from distances (**ranges**) measured from this point to some other known positions in space"*

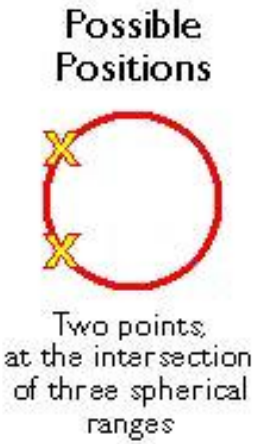


- O_1 and O_2 represent the Satellites of a GNSS system
- The receiver owned by Alice is at the point A
- The range *r* can be derived from a propagation-time (flight time, travel time) measurement τ,
- $r=c\cdot\tau$ (c=speed of light)

Ambiguity: Both A and B are solutions of the problem!

Let's do it 3D: Done !

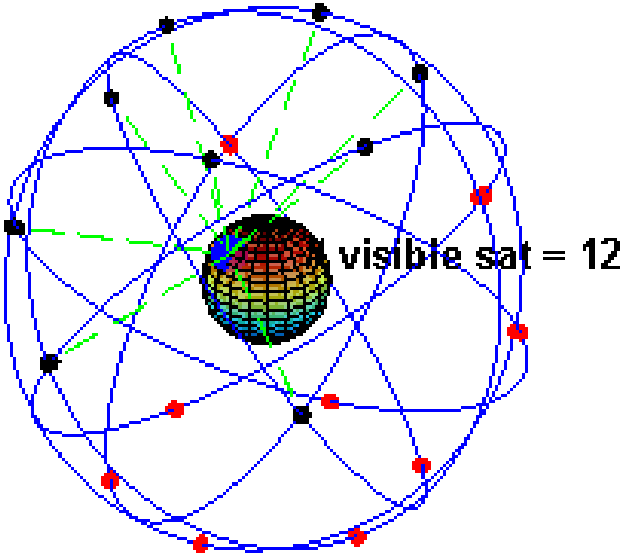




- **Not so simple… we'll see more later on**

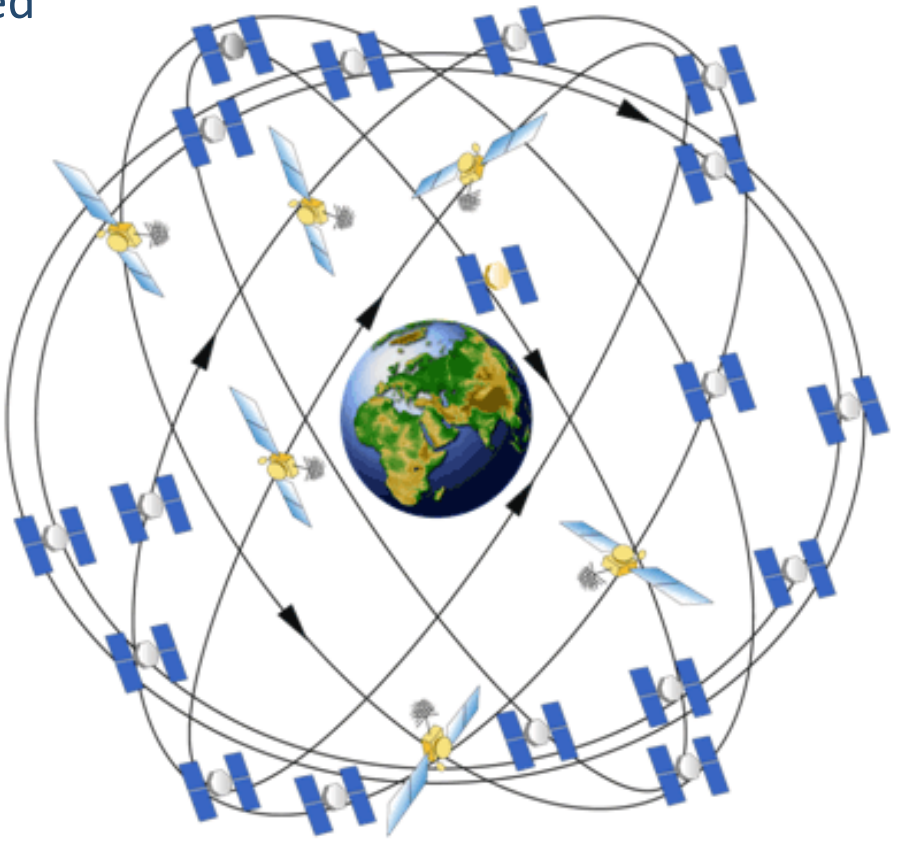
How does GPS work?

- GPS is a **global L-band broadcasting system** using different frequencies L1, L2, L5 on each satellite and **CDMA to allow frequency reuse** among satellites
- A **satellite-specific pseudo-random code** that is known to the receiver is sent out by each satellite
- By time-aligning a receiver-generated version and the receiver-measured version of the code, **the time of arrival (TOA) can be found** in the receiver clock time scale
- Each satellite also broadcasts a message that includes the **time of transmission of the code** (in GPS time scale) and the satellite position at that time
- With **four satellites** in view the system **time and 3D position** can be derived
- ***More details in next lecture..***



GPS Constellation

- 24 satellites nominally, 32 are operational
- (Almost) Circular Orbits on 6 equi-spaced planes
- Inclination of 55 degrees
- Altitude *h*=20,200 km
- Period (about) 12 hours (11h 58’ 2s)
- The 24-slot arrangement ensures users can view at least four satellites from virtually any point of the planet
- DS/SS Code division multiple access

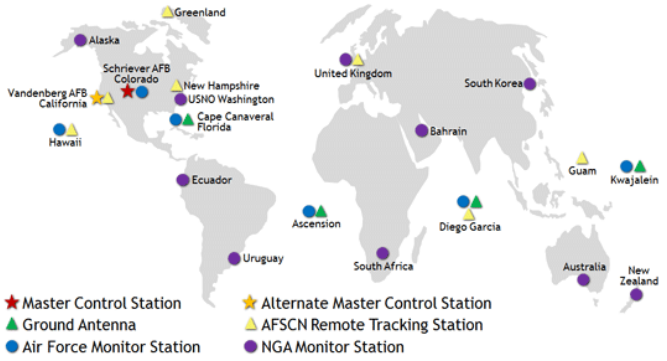


The Three *Segments* of GPS (GNSS)

- **The SPACE Segment**

– The space segment consists of a nominal constellation of 24 operating satellites that transmit one-way signals that give the current GPS satellite position and time

- **The CONTROL Segment**



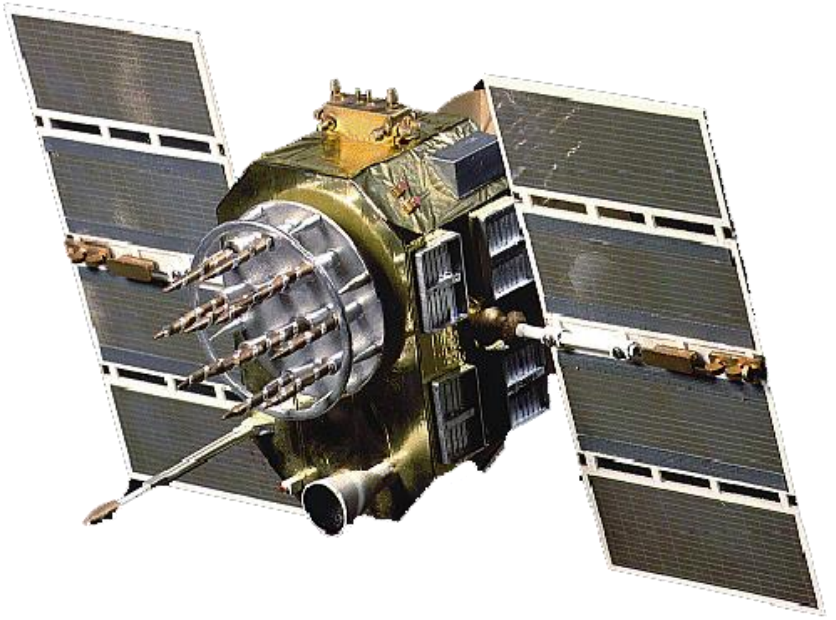
– The control segment consists of worldwide monitor and control stations that maintain the satellites in their proper orbits through occasional command maneuvers and adjust the satellite clocks. It tracks the GPS satellites, uploads updated navigational data, and maintains health and status of the satellite constellation

- **The USER Segment**

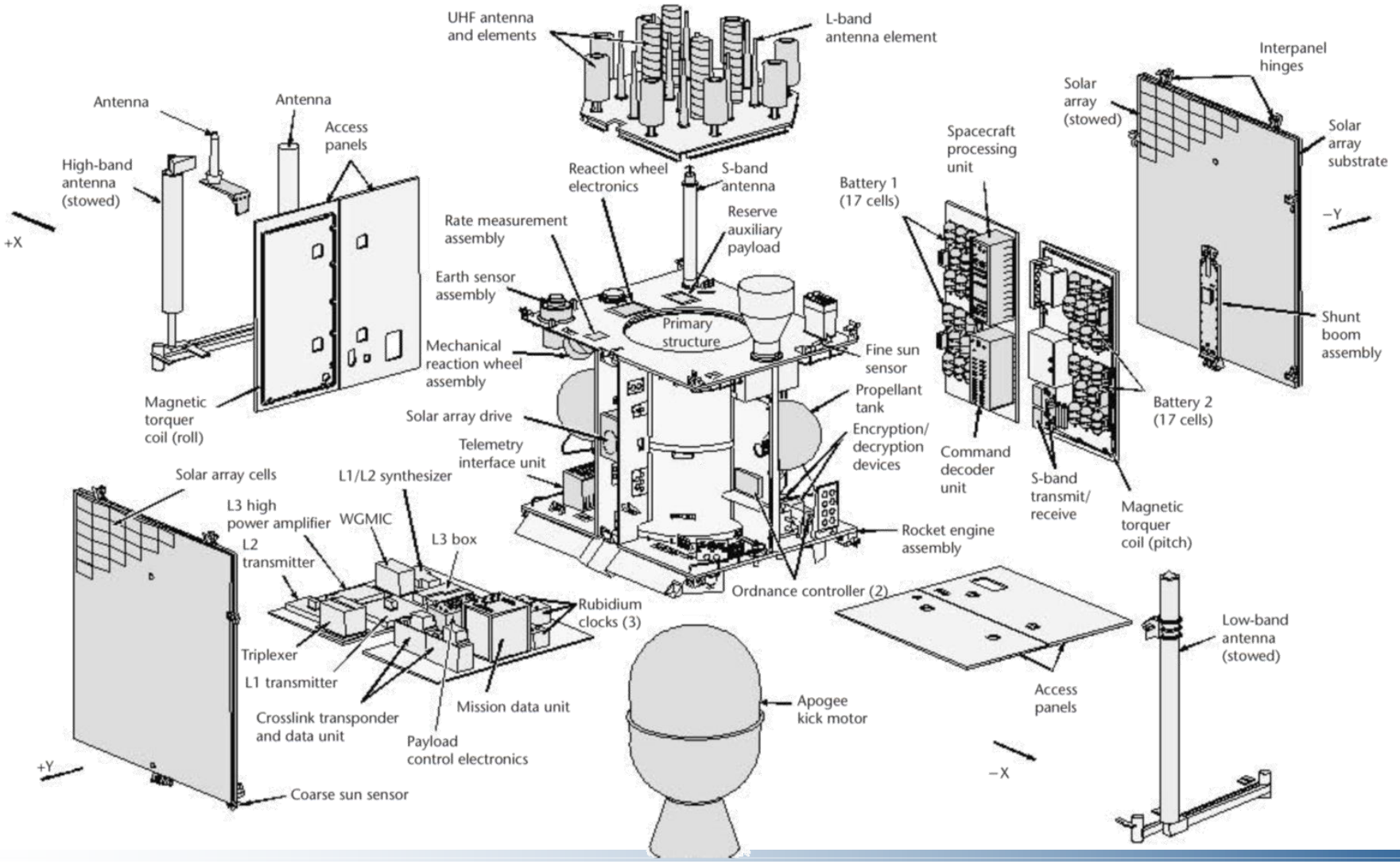
– The user segment consists of the GPS receiver equipment, which receives the signals from the GPS satellites and uses the transmitted information to calculate the user's three-dimensional position and time

GPS Block I Satellite (AD 1978)

- 3-axis stabilized spacecraft, nadir pointing using reaction wheels
- Dual solar arrays supplied over 400 watts (EOL) and charged NiCd batteries
- S-Band (SGLS) communications for control and telemetry
- UHF cross-links between spacecrafts
- A hydrazine propulsion system for orbital correction
- The payload included two L-Band navigation signals at 1575.42 MHz (L1) and 1227.60 MHz (L2)
- Block I satellites cost $ 20 million each
- In 1974 Rockwell was awarded a contract to build 8 satellites.



GPS Satellite



The GPS space segment evolution

Steerable beam for theatre of operations

GPS constellation status

Block	Launch period	Satellite launches				Currently in orbit and healthy
		Success	Failure	In preparation	Planned	
I	1978–1985	10	1	0	0	0
II	1989–1990	9	0	0	0	0
IIA	1990–1997	19	0	0	0	0
IIR	1997–2004	12	1	0	0	7
IIR-M	2005–2009	8	0	0	0	7
IIF	2010–2016	12	0	0	0	12
IIIA	2018–	6	0	4	0	6
IIIF	—	0	0	0	22	0
Total		76	2	4	22	32

(Last update: September 3, 2023)

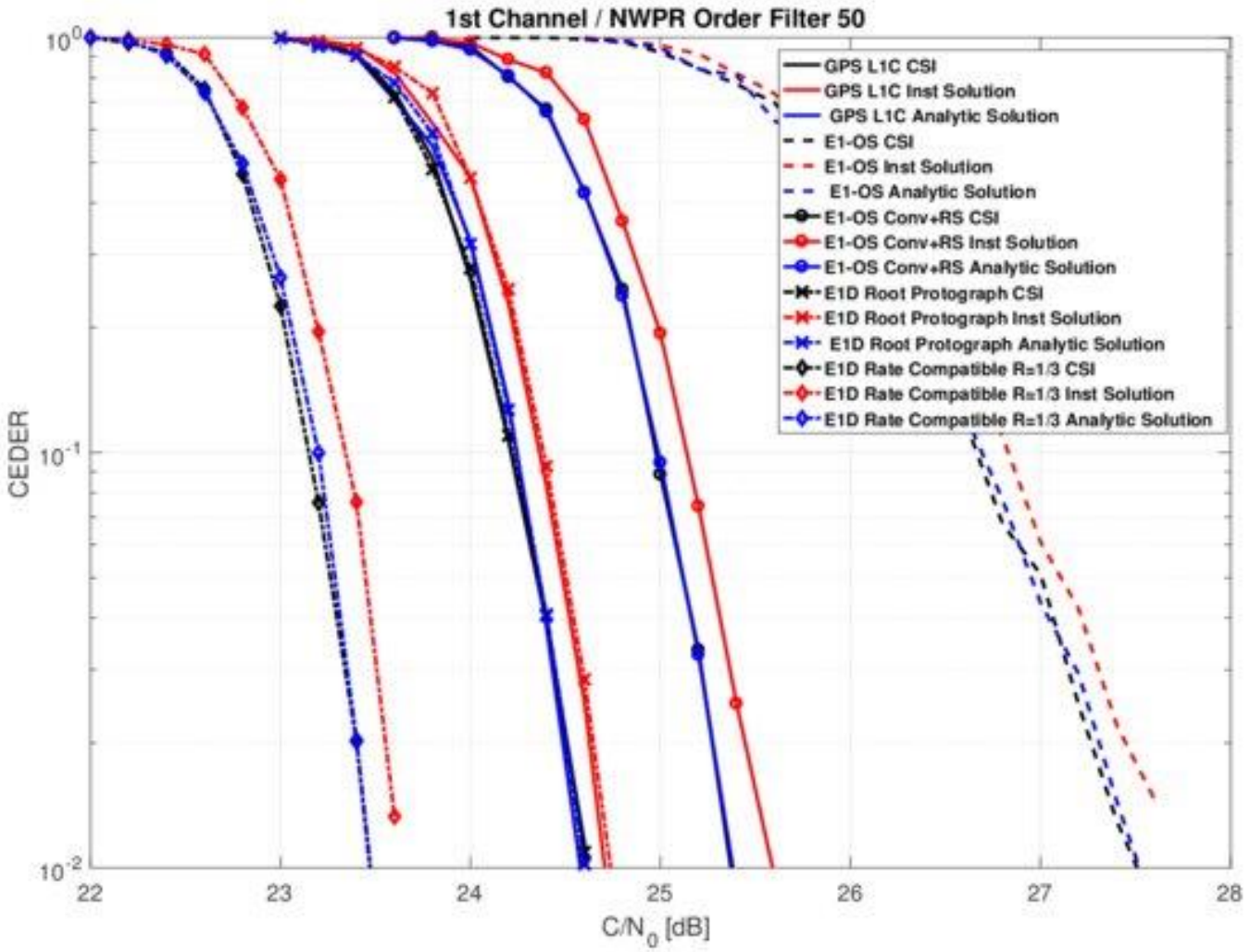
The GPS (GNSS) user segment evolution

GPS aeronautical terminal AD 1977

GNSS multi-constellation chip AD 2020+

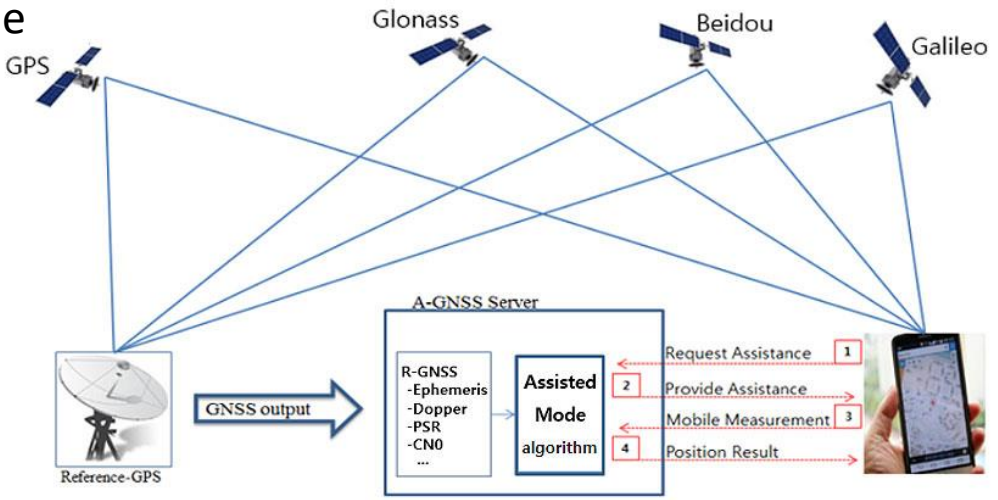
GNSS navigation message decoding AWGN channel

CED = Clock and Ephemeris Data



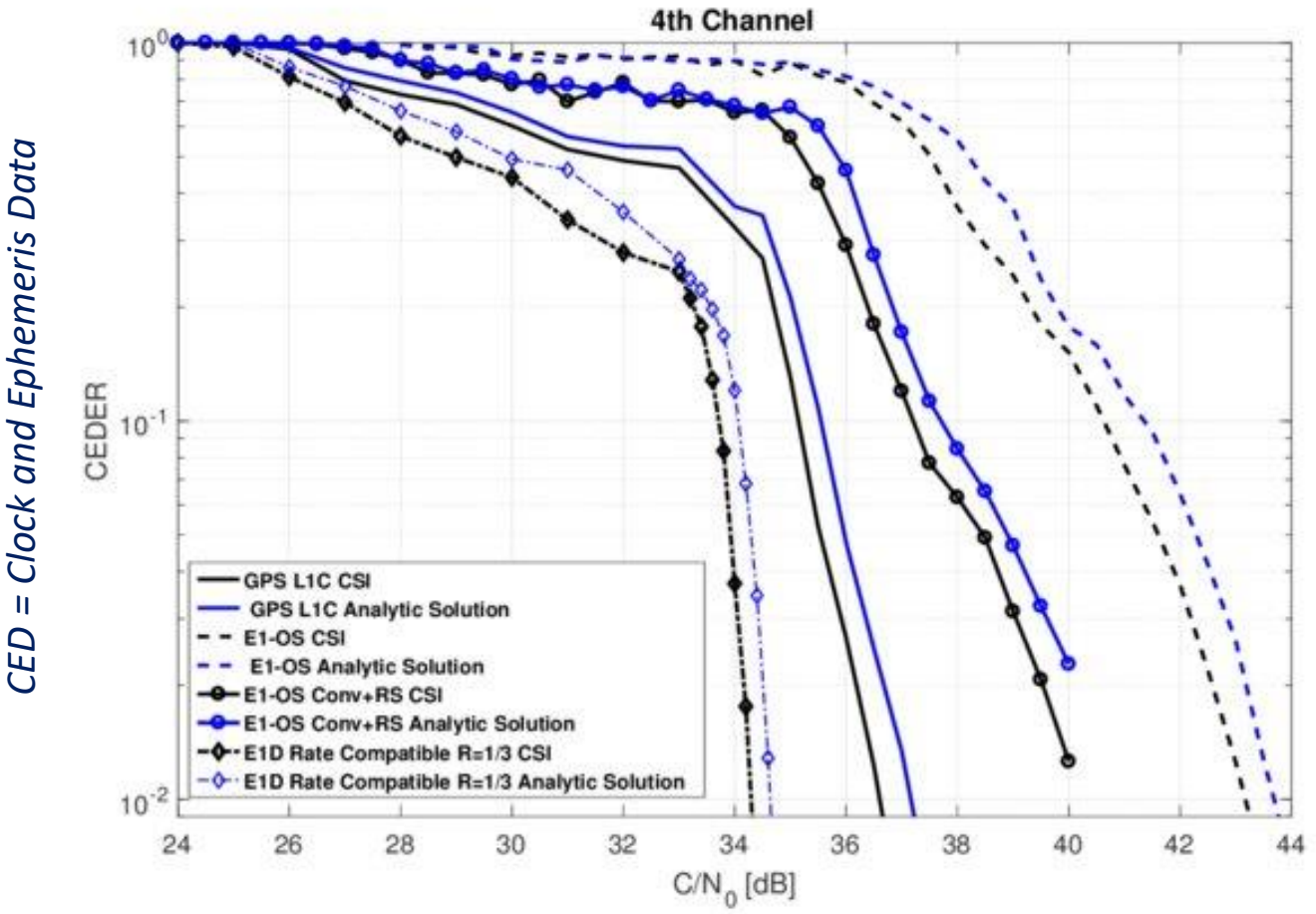
The GPS (GNSS) user segment evolution - GPS goes to your pocket…

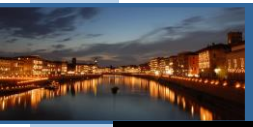
- **A major innovation in the field of PNT has been the introduction of A-GNSS:**
  - While the GNSS DS/SS codes can be tracked down to very low C/N_0 (e.g. 10 dBHz)
  - The same is not true for the navigation message data (uncoded in GPS before GPS-III and with FEC+interelaving in Galileo – see next slide)
  - The terrestrial cellular network can assist the mobile in acquiring the GNSS signals and providing the navigation messages to the hand-held via a A-GNSS server
  - Faster & more reliable



GNSS navigation message decoding – urban channel

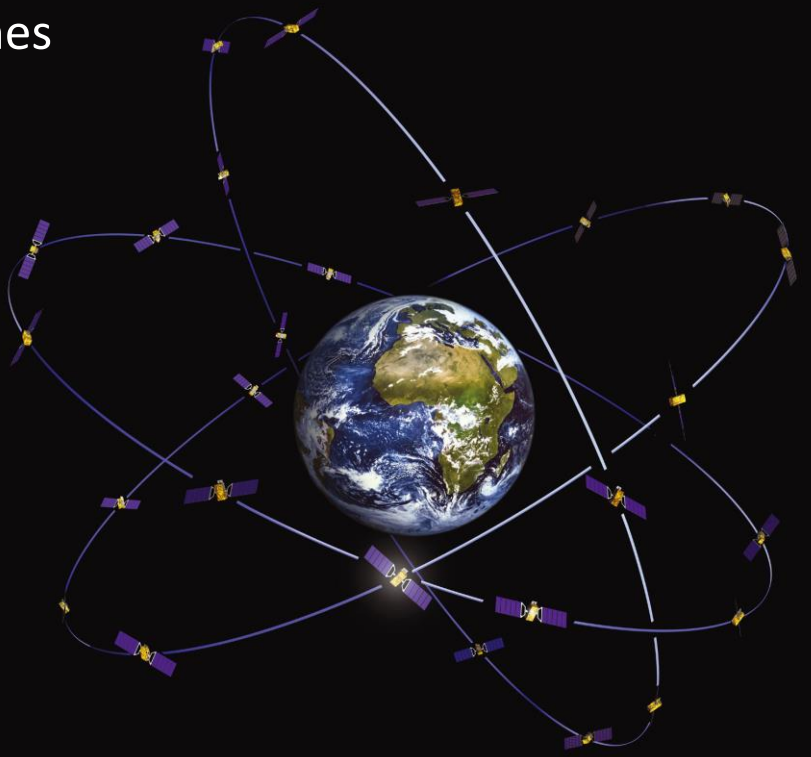
Urban fading channel modelled through the 2-state Prieto channel for a vehicle speed of 40 km/h and an elevation angle of 40 degrees





GALILEO Constellation

- Nominally 24 satellites (+6 spares) – 23 operational
- Circular Orbits on 3 equi-spaced planes
- Inclination of 56 degrees
- Altitude *h*=23,222 km
- Period (about) 14 hours
- Better coverage of high-latitudes than GPS
- DS/SS Code Division Multiple Access



ГЛОНАСС - GLONASS

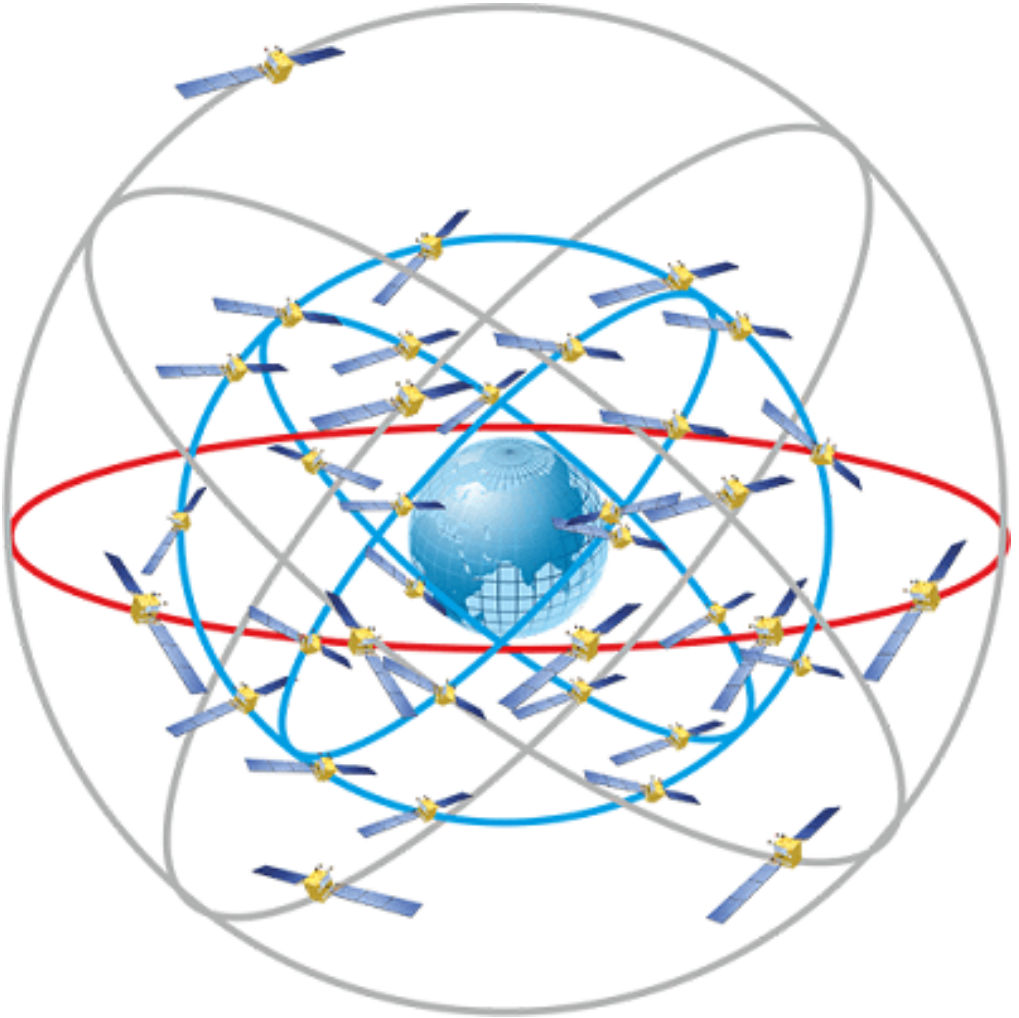
GLONASS is the Russian GNSS

- 24 satellites (operational)
- Circular Orbits on 3 equi-spaced planes
- Inclination of 64.8 degrees
- Altitude *h*=19,100 km
- Period (about) 11 hours 15 minutes
- Good coverage at high latitudes
- DS/SS FDMA and CDMA

Beidou (Big Dipper, Grande Carro)

Beidou is the Chinese GNSS

- 7 GEO
- 10 Inclined GSO (IGSO) satellites at 218E,98E,338E intersecting at 118E with 55-degree inclination
- 27 MEO satellites on 3 equi-spaced orbital planes (GPS-like) at 21,500 km altitude, period 12h 52 min
- DS/SS CDMA

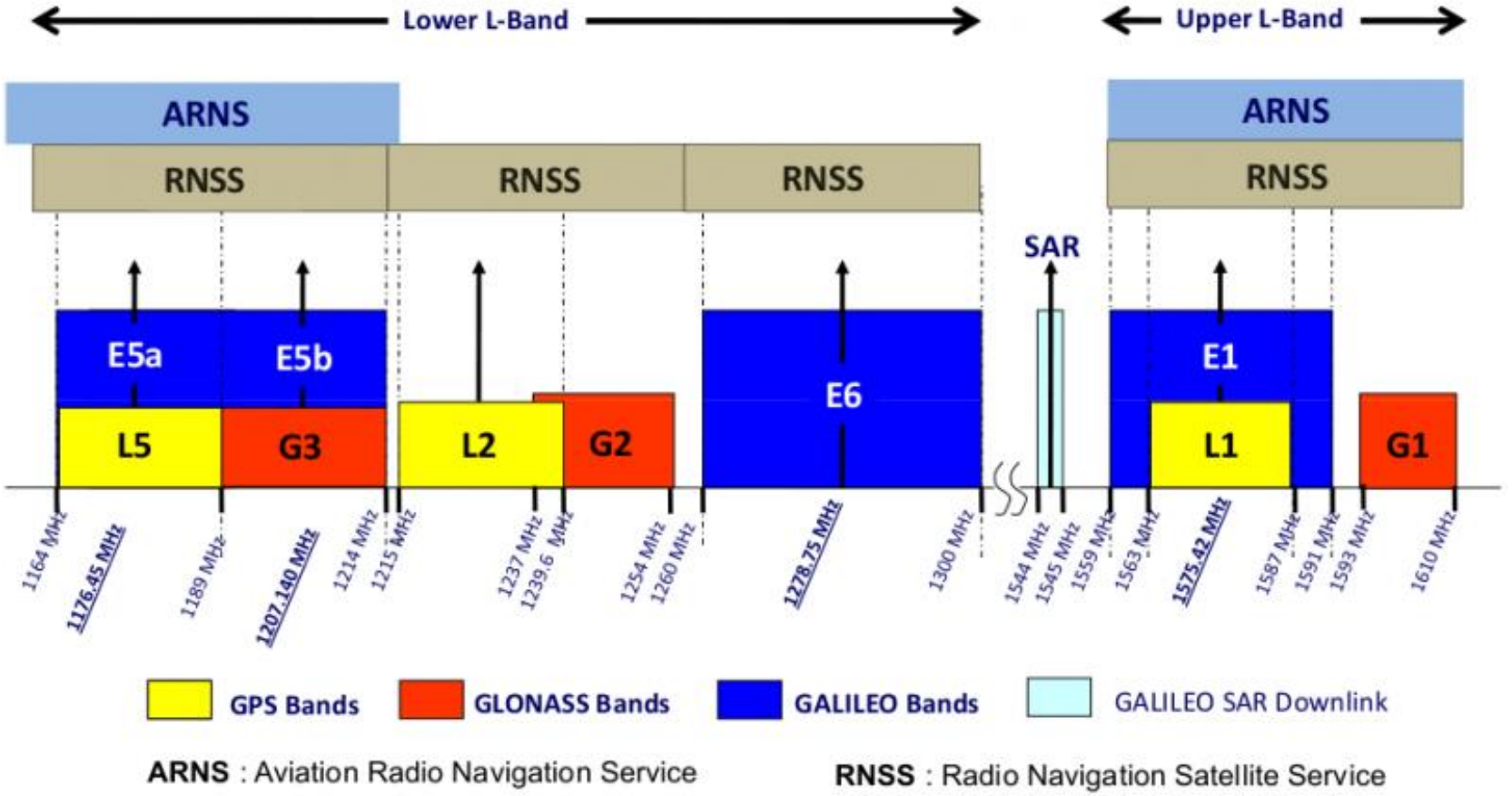


Regional NSS (RNSS)

- **IRNSS (Indian RNSS) aka NAVIC (Navigation Indian Constellation)**
  - Independent and autonomous regional navigation system aiming a service area of about 1500 kilometers around India
  - The system is under complete Indian control
  - 3 GEO + 4 IGSO satellites with appropriate Ground Segment

- **QZSS (Quasi-Zenithal Satellite System - Japan)**
  - The primary purpose of QZSS is to improve on the availability of GPS in *urban canyons*, where only satellites at very high elevation can be seen
  - 5 Tundra-type highly inclined, slightly elliptical, geosynchronous orbits (4 operational) satellites with appropriate Ground Segment
  - It is intended to interoperate with GPS/GALILEO

GNSS frequency bands



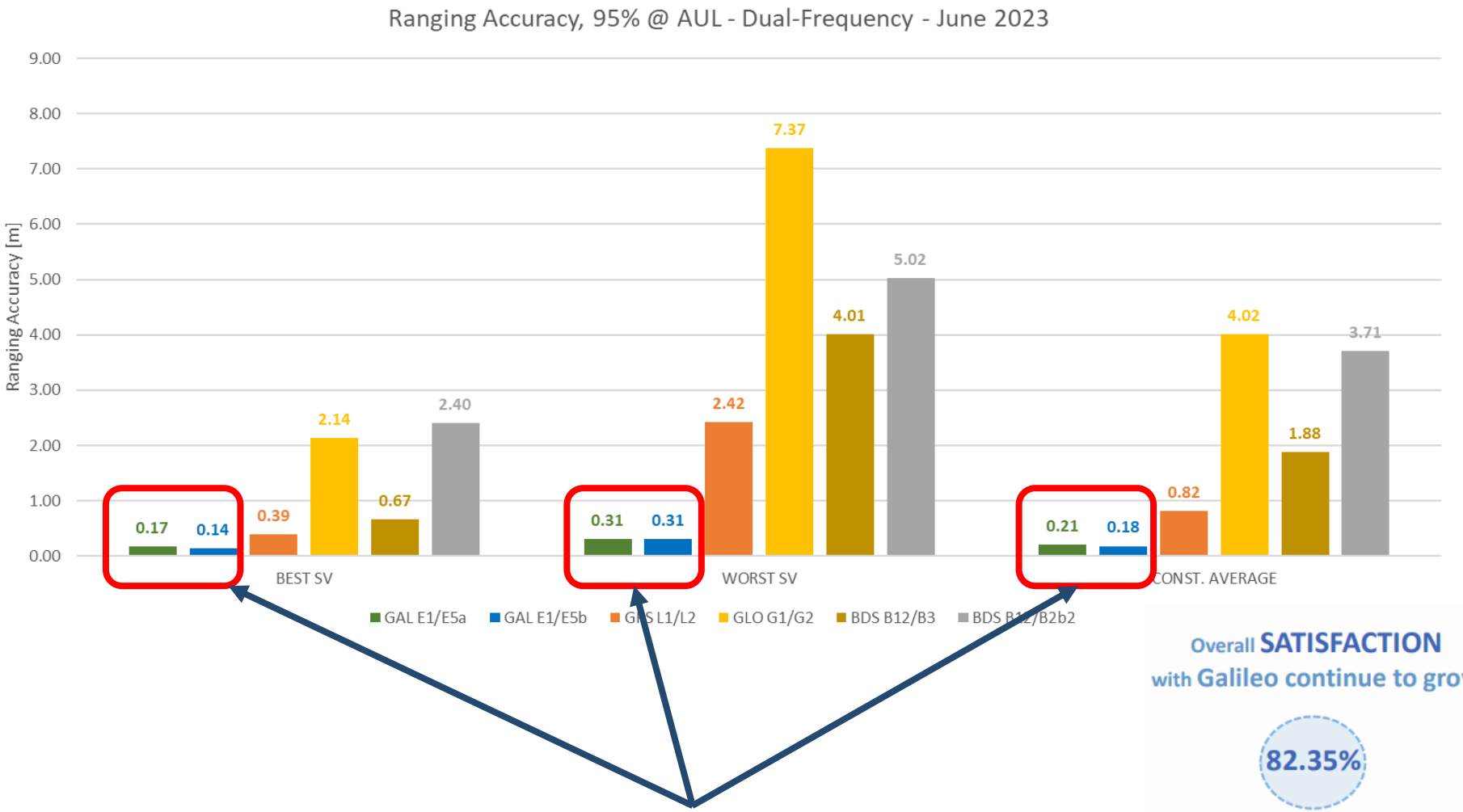
GALILEO, the European GPS – a troubled start

- **Key GALILEO program steps**
  - In 1999, the different concepts of the three main contributors of the EU/ESA program (Germany, France and Italy) for Galileo were compared and reduced to one by a joint team of engineers from all three countries.
  - The first stage of the Galileo programme was agreed upon officially in May 2003 by the European Union and the European Space Agency.
  - The first experimental satellite, GIOVE-A, was launched in December 2005 and was followed by a second test satellite, GIOVE-B, launched in April 2008.
  - The system was planned to become operational in 2013 (2014).
  - In mid-2006, the public-private partnership (PPP) fell apart, and the European Commission decided to nationalise the Galileo programme.
  - In April 2008, the EU transport ministers approved the Galileo Implementation Regulation. This allowed the €3.4 billion to be released from the EU's agriculture and administration budgets to allow the issuing of contracts to start construction of the ground station and the satellites.

GALILEO, the European GPS – a troubled start

- **Key GALILEO program steps (cntd):**
  - In October 2009, the European Commission cut the number of satellites definitively planned from 28 to 22, with plans to order the remaining six at a later time.
  - In July 2010, the European Commission estimated further delays and additional costs of the project to grow up to €1.5–1.7 billion and moved the estimated date of completion to 2018.
  - After completion, the system will need to be subsidised by governments at €750 million per year.
  - An additional €1.9 billion was planned to be spent bringing the system up to the full complement of 30 satellites (27 operational + 3 active spares).
  - The space segment suffered failures of some clocks (both Rubidium and Passive Hydrogen Maser) and one antenna due to Corona effects.
  - The last batch (B3) of satellites launch was interrupted due to Ukraine war not making possible to launch using the Soyuz Russian launcher from Kourou.

GALILEO the European GPS – performance matter!



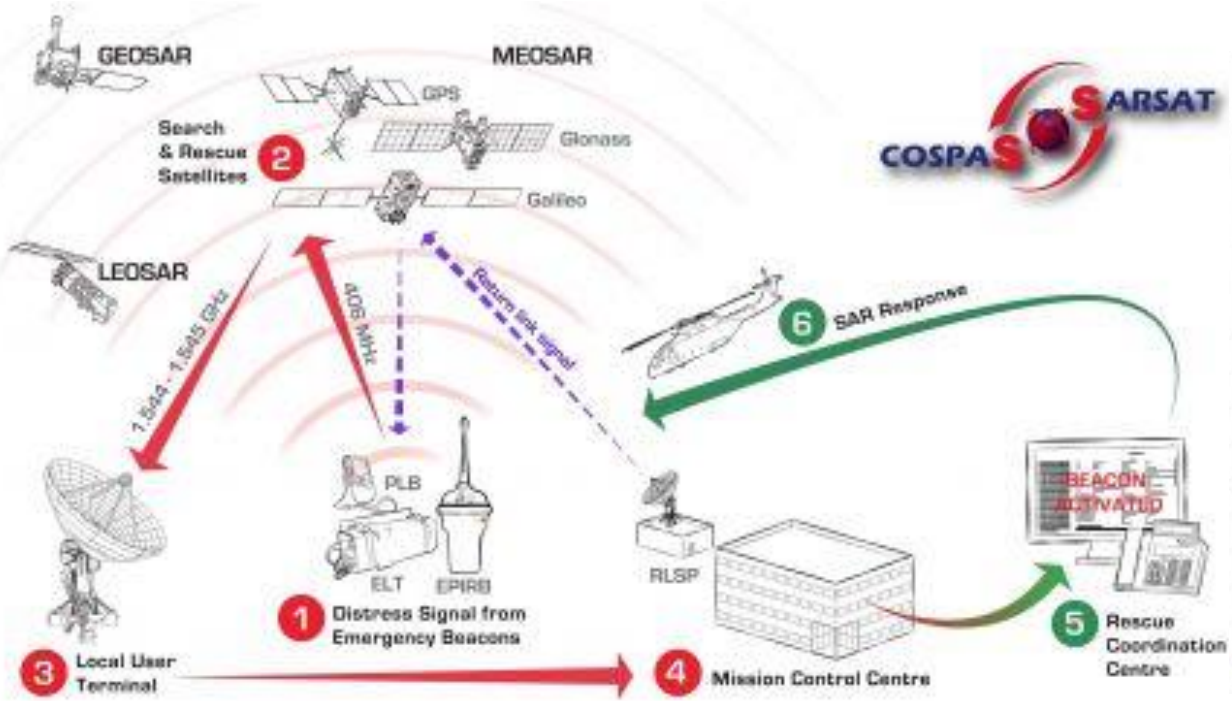
Overall **SATISFACTION** with Galileo continue to grow

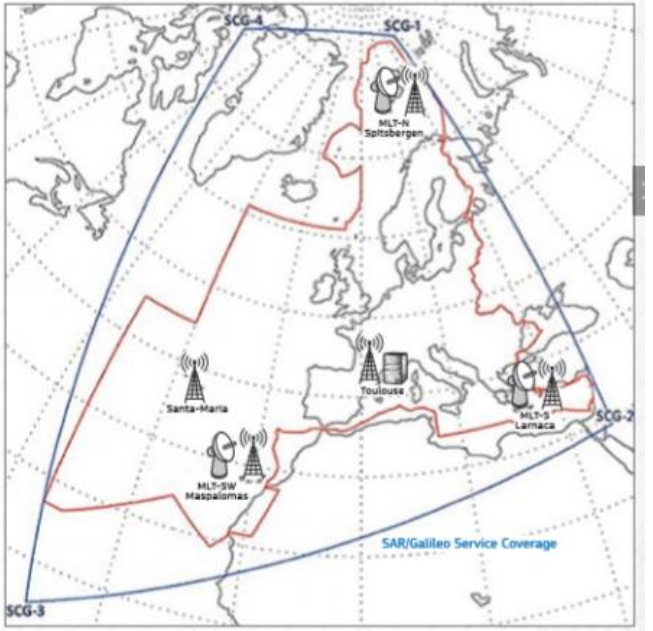
82.35%

Galileo has the best performance among GNSS constellations

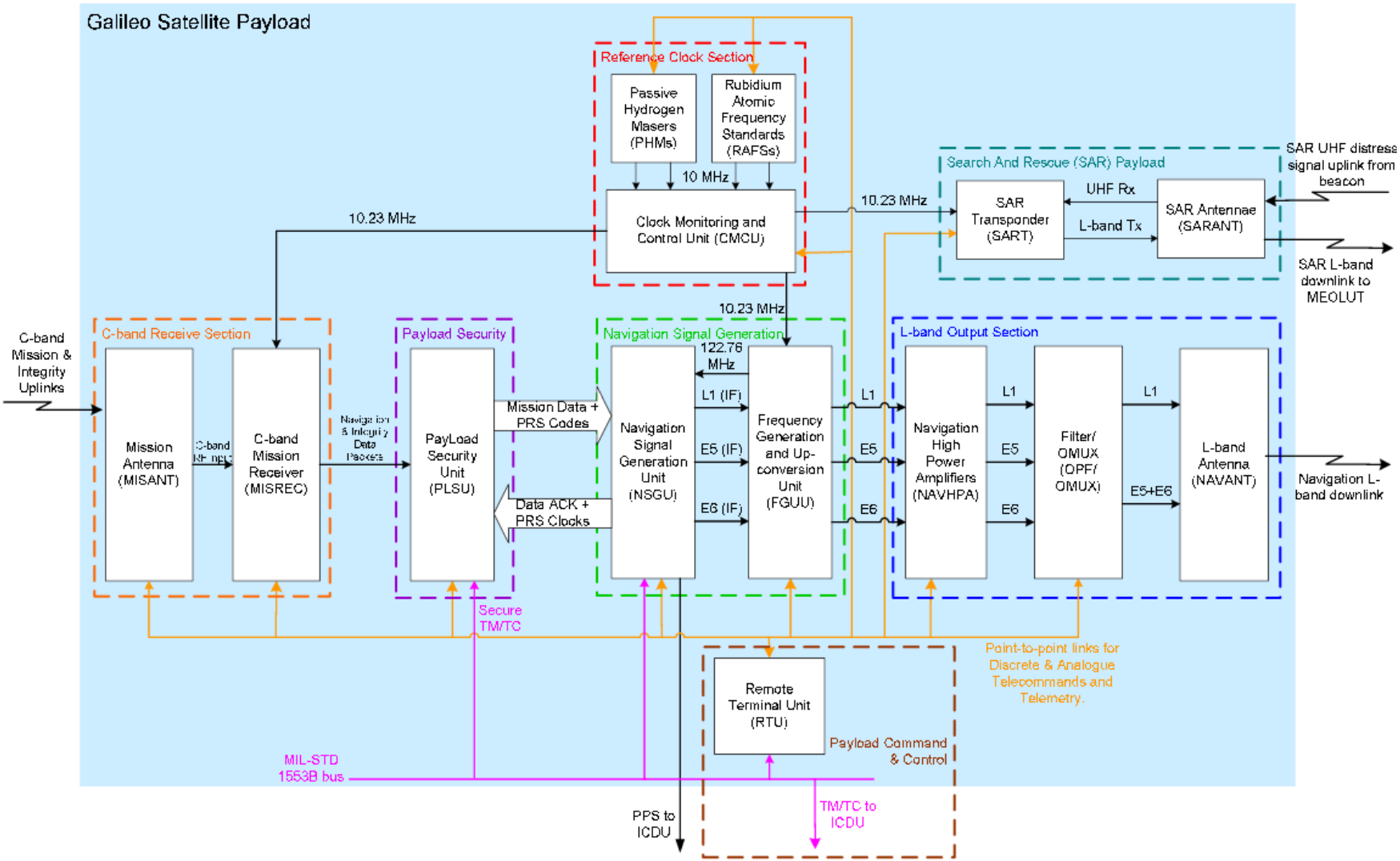
Galileo not only for PNT – The Search and Rescue Service

- **Galileo contributes to the COSPAS-SARSAT Search and Rescue global system**
  - UHF distress messages send by users with a small SAR teminal operating in UHF
  - Galileo is receiving the distress signals and downlinking the gateways
  - SAR response now provided in Galileo E1B signal

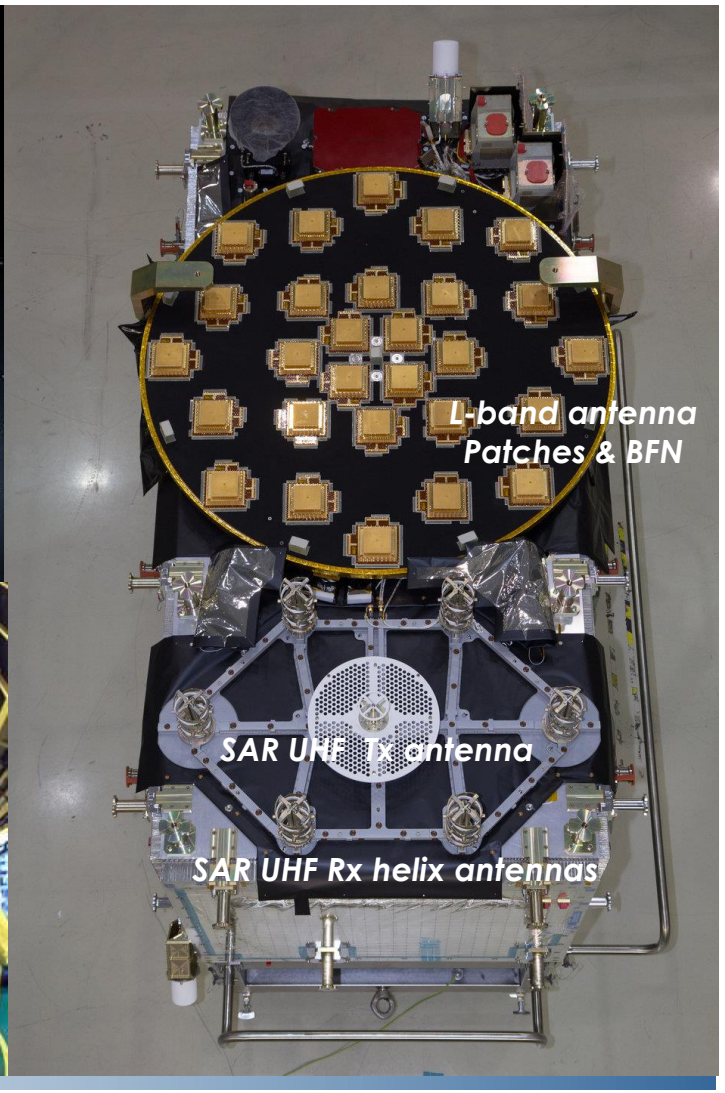




GALILEO Space Segment 1/6

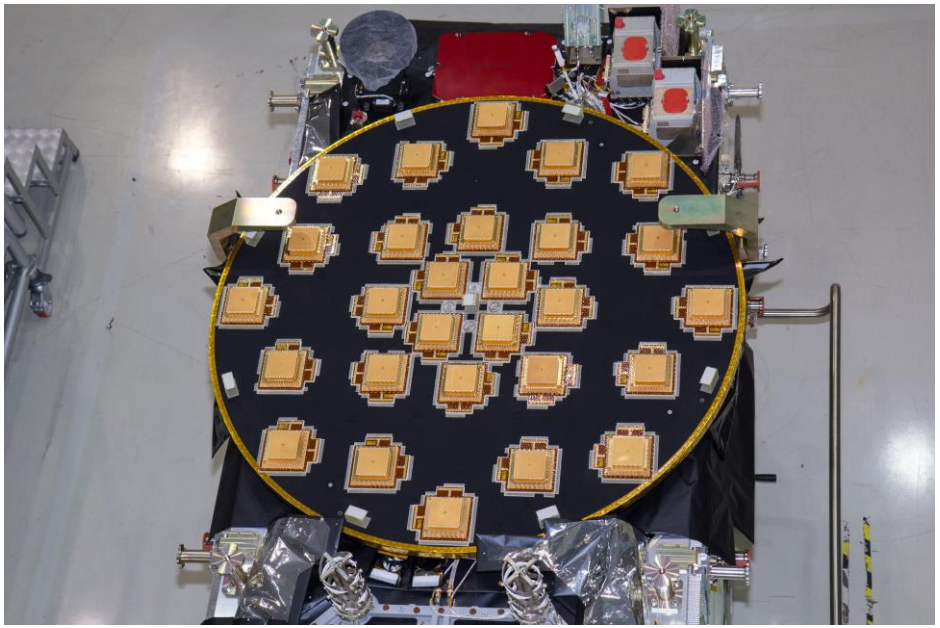


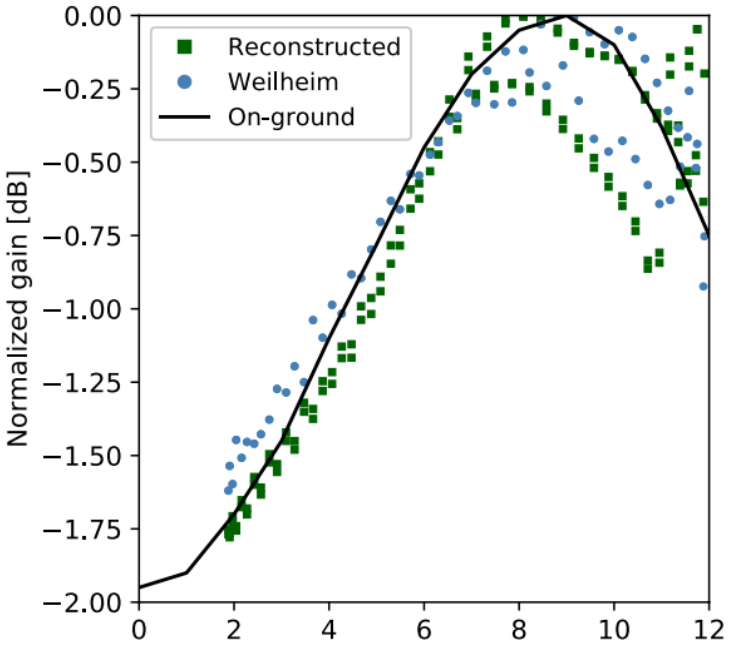
GALILEO Space Segment 2/6



GALILEO Space Segment 3/6

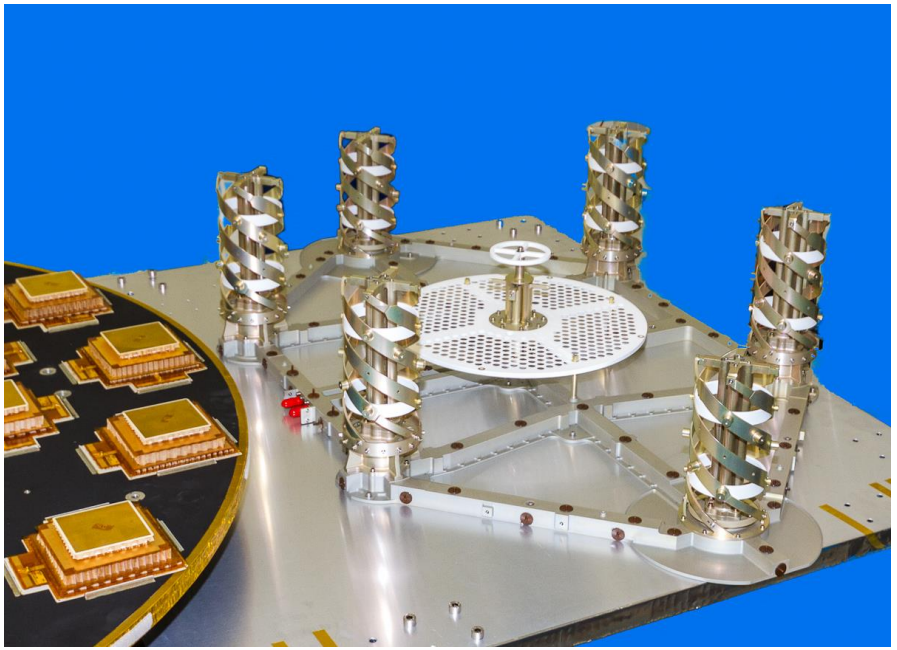
- **NAVANT – The Galileo Navigation Antenna**
  - Three bands supported: E1, E5, E6
  - Array with passive beam forming network and patch feeds
  - Isoflux pattern
  - High fidelity in terms of group delay/phase center





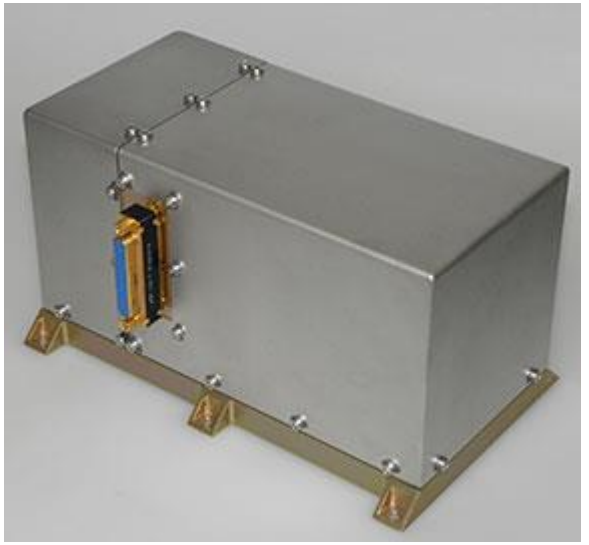
GALILEO Space Segment 4/6

The SART payload for Search and Rescue



GALILEO Space Segment 5/6

The Passive Hydrogen Maser Clock



The Rubidium Clock

GALILEO Space Segment 6/6

The Clock Monitoring and Control Unit

The Frequency Generation and Upconversion Unit (FGUU)

The Navigation Signal Generation Unit (NSGU)

GALILEO Ground (Control) Segment 1/7

GALILEO Ground Segment 2/7

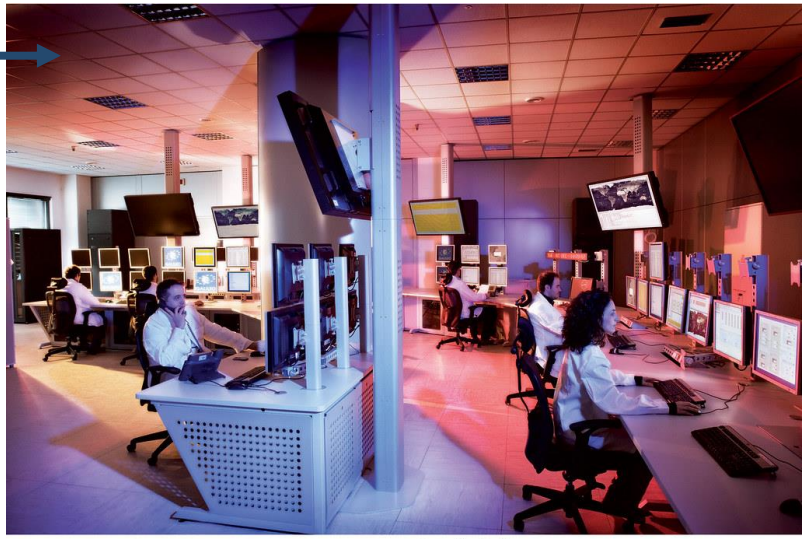
- The Galileo ground segment consists of two **Galileo Control Centres** (GCC) situated in Oberpfaffenhofen (Germany) and Fucino (Italy).

- Each GCC manages 'control' functions supported by a **Ground Control Segment (GCS)** and 'mission' functions, supported by a dedicated **Ground Mission Segment (GMS)**:
  - The **GCS** handles **spacecraft housekeeping and constellation maintenance** by means of the **network of TT&Cs stations** globally distributed. The scope of this functionality includes control and monitoring of the satellites and payload, planning and automation functions that allow safe and correct operations to take place and the support of payload related operations.
  - The **GMS** determines the **navigation and timing data part of the navigation messages** by means of the network of GSSs (GALILEO Sensor Stations). The GMS communicates with the Galileo satellites through the network of ULSs.

GALILEO Ground Segment 3/7

Control Center, Oberpfaffenhofen (D)

Control Center, Fucino (I)



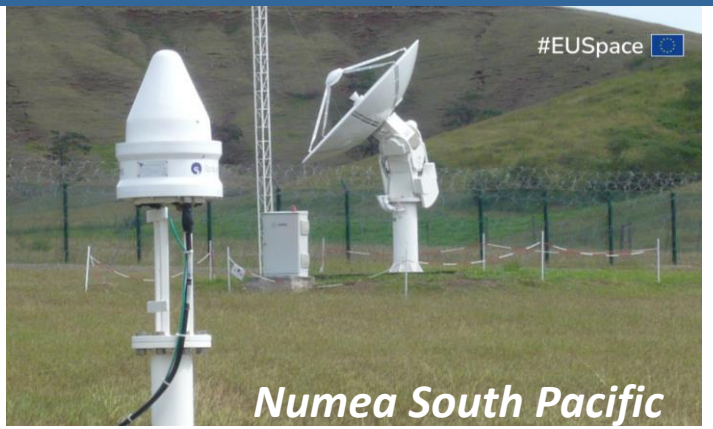
Control Room, Galileo Control Centre at Fucino (Italy) / Sala Controllo Centro di Controllo Galileo al Fucino (Italia) ©Telespazio

GALILEO Ground Segment 4/7

- The GMS and GCS interface the satellites with a worldwide network of ground stations implementing monitoring and control functions:
  - **Galileo Sensor Stations (GSS)**, which collect and forward Galileo SIS measurements and data to the GCCs in real time
  - **Galileo Uplink Stations (ULS)**, which distribute and uplink the mission data to the Galileo constellation.
  - **Telemetry, Tracking & Control stations (TT&C)**, which collect, and forwards telemetry data generated by the Galileo satellites, and distribute and uplinks the control commands required to maintain the Galileo satellites and constellation.

GALILEO Ground Segment 5/7

Sensor Stations: Gran Canaria



Numea South Pacific

L-band SS Rx antenna: why omni-directional?

Svalbard

GALILEO Ground Segment 6/7

GALILEO Ground Segment 7/7

- The Galileo core infrastructure is complemented by services facilities which support the provision of the Galileo services:
  - The **European GNSS Service Centre (GSC):** is the interface between the Galileo Initial OS and CS user communities and the Galileo system
  - The **Geodetic Reference Service Provider (GRSP):** supports the GCC in realising the Geodetic Reference Service Provider (GTRF)
  - The **Time Service Provider (TSP):** supports the GCC in the realisation of the Galileo System Time (GST)
  - The **Galileo Security Monitoring Centre (GSMC):** in charge of monitoring the system security @ St. Germain-en-Laye (France) and Madrid
  - The **SAR/Galileo Data Service Provider (SGDSP):** is the entity in charge of the coordination of the operations related to the SAR/Galileo service @ Toulouse
  - The **Galileo Reference Centre (GRC):** is responsible for independent monitoring and assessment of the performance of the Galileo services @ Noordwijk (The Netherlands).

GALILEO Complementary Ground Infrastructure

GNSS Services: GALILEO 1/2

- **Open Service**
  - Mass-Market applications not requiring any guarantee.
  - As accurate as conventional differential GPS but without requiring additional ground infrastructure.
  - Horizontal Accuracy: 4 meters, 95% confidence (specified)
  - Vertical Accuracy: 8 meters, 95% confidence (specified)
- **Safety of Life Service:**
  - Guaranteed service for Safety-of-Life applications
  - Integrity Alerts
- **Commercial Service:**
  - Professional use and guaranteed service in return of a fee
  - System capabilities introduced to foster application with commercial interest (additional navigation signals, low-data rate broadcasting capacity).

GNSS Services: GALILEO 2/2

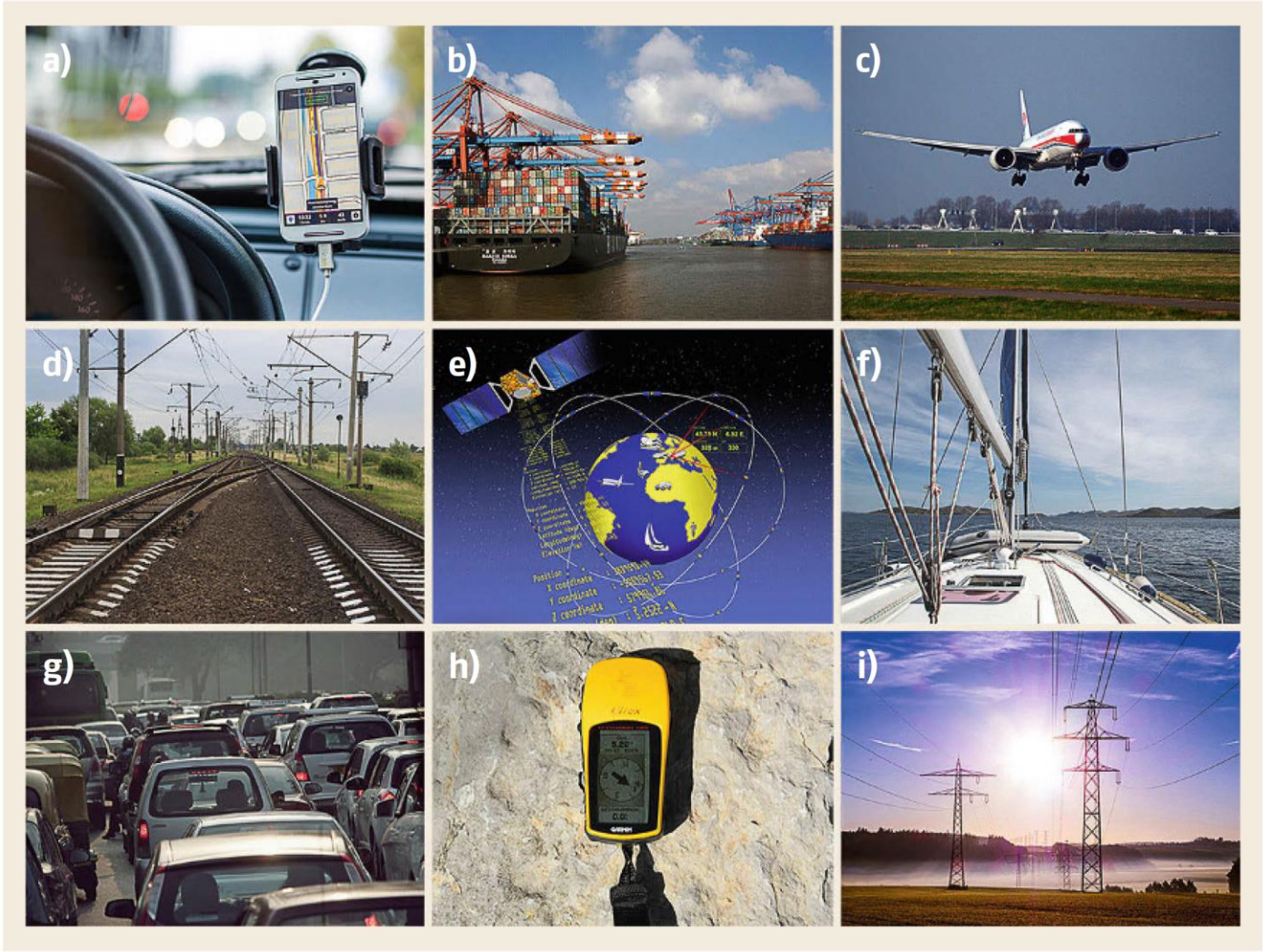
- **Public Regulated Service:**
  - Police, coast guards, customs, strategic civil infrastructure, military…
  - High continuity of service.
  - Signals more robust to interference.
  - Access to the service to government authorized-users only.
- **Search and Rescue Service:**
  - Relay of distress alarms to improve existing relief and rescue services.
  - Compatible with COSPAS-SARSAT

GNSS Application Examples – Mass Market

Transportation, Construction, Energy

Public, Private, Safety-Of-Life applications not excluded

Internet of Things in general



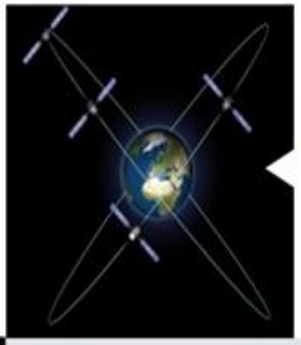
GNSS Application Examples – Precision Applications

Geodesy, Earth Observation & Earth Sciences, Agriculture, Coastal Monitoring, Landslides etc.

GALILEO Development Status

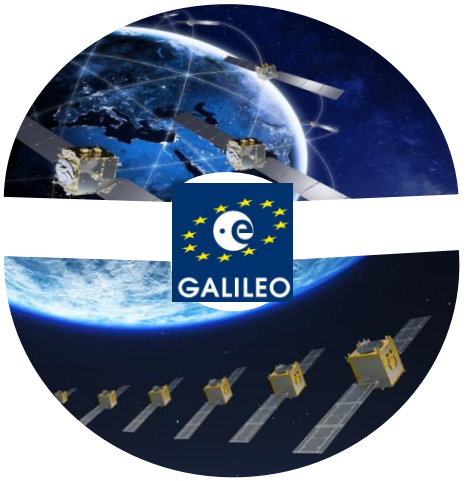
GALILEO

2005
DEVELOPMENT SYSTEM TESTBED
GIOVE A/B



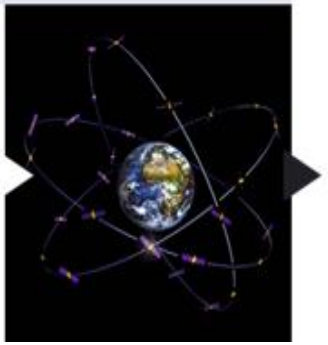
2013
IN-ORBIT VALIDATION
4 satellites
initial ground infrastructure

2015/2016
INITIAL GALILEO SERVICES
OS, SAR, PRS, CS demonstrator



2017/2019
EXPLOITATION PHASE
FOC1 System

2023+
FULL OPERATIONAL CAPABILITY
24 operational satellites
and complete ground infrastructure

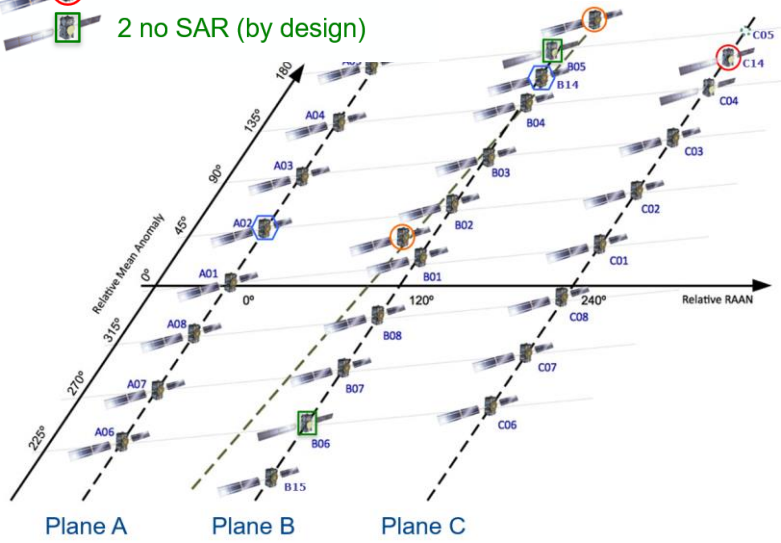


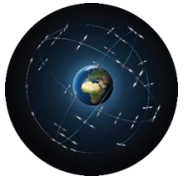
TOWARD GALILEO 2nd GENERATION

G2G

Galileo G1 Constellation Status

28 satellites in orbit
2 unhealthy (NAV P/L only)
2 inactive spares
1 unavailable
2 no SAR (by design)





28 Satellites | 23 set USABLE

Satellite Family	S/C in orbit	S/C set USABLE	Average Age (years)	Oldest S/C (years)
IOV	4 →	3 →	11.3	11.8
FOC WO1/WO2	22 →	18 →	6.8	8.9
FOC Batch#3	2 →	2 →	1.7	1.7
TOTAL	*28* →	*23* →	*7.1*	*11.8*

As of 1st Aug 2023

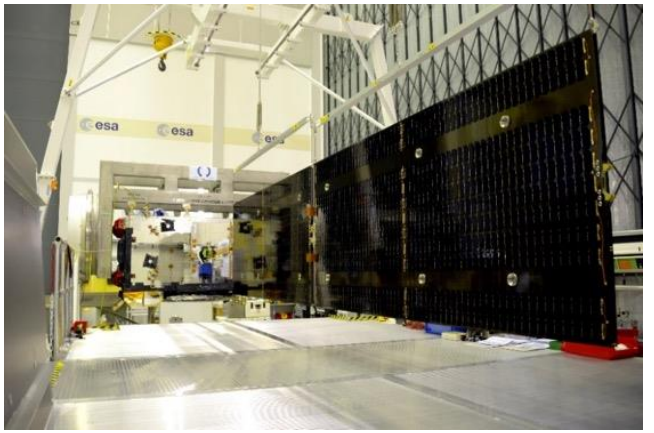
↓→↑ : *trend wrt May-23*

Q2/2023 Statistics
SISE FNAV DF values computed at average user location (SISE Global Average)

Satellites SISE RMS daily statistics		Constellation SISE RMS daily statistics		Monthly SISE 95% statistics	
BEST SAT	WORST SAT	BEST DAY	WORST DAY	BEST SAT	WORST SAT
GSAT0212 0.037m 9th May 2023	GSAT0101 1.47m 4th June 2023	0.110m 24th May 2023	0.33m 4th June 2023	GSAT0213 0.18m May 2023	GSAT0101 0.36m April 2023

Galileo G1 Space Segment Development Status

L11 (FM23 & FM24)	FM23 & FM24 providing Service in orbit
L12 (FM25 & FM26)	L12 launch campaign postponed; in storage.
L13 (FM27 & FM28)	Acceptance Review completed; in storage.
L14 (FM29 & FM32)	Acceptance Review completed; in storage.
L15 (FM31 & FM33)	Acceptance Review completed; in storage.
L16 (FM30 & FM34)	Acceptance Review completed on 22 June 2023; in storage.

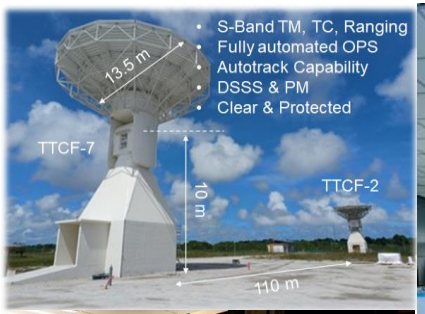


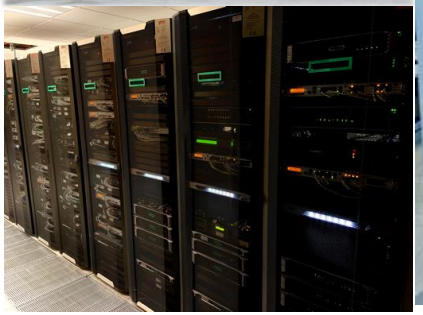
Solar Array deployment test in cleanroom

Batch 3 Sat's *in* Storage at OHB Bremen

Autocompatibility testing in anechoic chamber

Galileo G1 Ground Segment Status





- *Roll-out of System infrastructure in support to Open Service Final Operational Capability.*
- *Globally distributed Cyber Security Monitoring infrastructure implemented.*
- *Deployment of PRS infrastructure in order to enable Initial Operational Capability, currently under final stages of validation/deployment.*

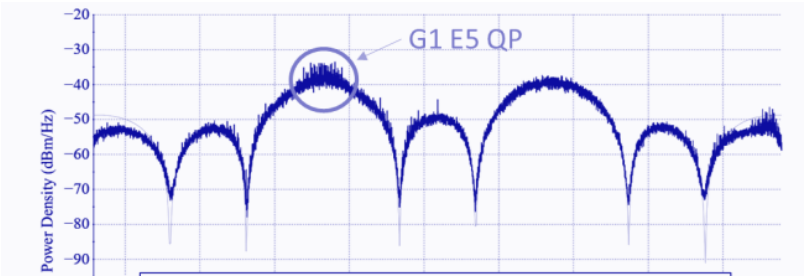
- *2nd Kourou TT&C Station installed (TTCF-7).*
- *Ground Control Segment upgraded with improved robustness and virtualization capabilities.*
- *New Mission Monitoring Facility developed to improve mission and services monitoring (GRF).*

Galileo G1 SIS INAV improvements and new Pilot Signal

- New Reduced Clock and Ephemeris Data.
- Reed Solomon Outer Forward Error Correction.
- Secondary Synchronisation Pattern.

Ready

Faster TTFF and increased robustness

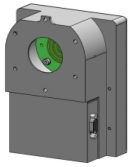


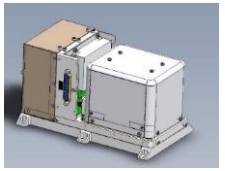
- New Test signals on GSAT 201 and 202
- Additional short pilot signal on E5 added
- Achievable trough simple space segment SW update

Faster and simplified E5 acquisition – not available in GPS

Programme Decision pending receiver manufacturers consultation and testing

Galileo Second Generation Procurements





G2G B1 – ADS-DE Satellite
Critical Design Review under preparation
EM Antenna Testing ongoing

G2G Satellite Clocks
2 Operational, 2 Evolutions & 1 Experimental clocks ongoing

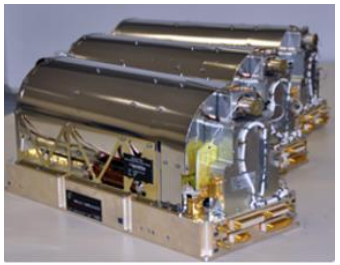
G2G B1 – TAS-IT Satellite
Critical Design Review about to start
Structural Models & EM payload tested

G2G System Eng & Tools
System Support activities contracted.
Tools and R&D ongoing.

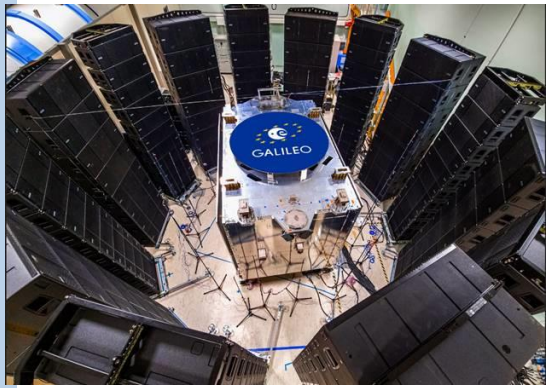
G2G Ground Segment & System Test Beds
7 G2G In Orbit Validation Ground Segment & System Test Beds procurements started.

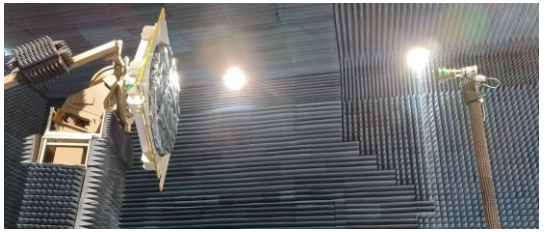
Dip. Ingegneria dell'Informazione
University of Pisa, Italy

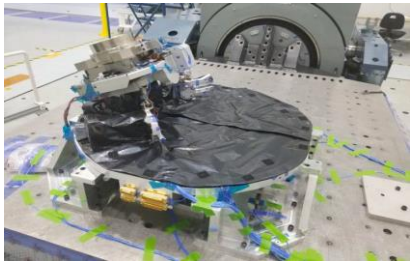
G2G Space Segment Production at full speed



G2G Clock Farm







G2A: Acoustic & Vibration tests performed in Rome.

EM Payload, Structural Model 1 & 2 in ESTEC.

G2B: EM antenna testing ongoing.

Critical Unit testing ISL & SBand achieved.

G2G Ground Segment and System Engineering
1B€ contracts committed in 1st half 2023

G2G Ground Control

G2G System Engineering Technical Assistance

G2G Industry Primes - European Navigation Conference (ENC 2023)

G2G Ground Mission

G2G System Test Bed

G2G Security Monitoring

G2G Ground Segment Key Features

Manage 2 new G2 S/C Platforms with Intersatellite Links

… providing new capabilities and services.

- Supporting new platform and flexible payload capabilities.
- Implementing Inter-satellite Links (ISL) and associated operational concept.
  - Improving factor 4 positioning performance.
  - Increasing flexibility for new services.
- New G2 Early Services

Implement Electric Orbit Raising

… for more efficient launches.

- Implement the flight dynamics algorithms and strategies for the implementation of manoeuvres and orbit determination.
- Improve the planning and operational concept to accommodate operations during larger transference phases.

Fasten System Integration

… supported by intermediate releases.

- Incremental development and deployment concept to avoid delays on capabilities.
- Perform Radio Frequency Compatibility and System Test Campaigns to ensure compatibility with the new S/C to be launched.

New S-Band High Speed Modes

… implementing new Ground to Space interfaces

- Supporting new Ground to Space Protocols based on CCSDS Standards.
- Supporting new RF modulation modes through the deployment of new BBMs.
- Supporting new data rates and inter-satellite data transfers.

G2G Future Services

Open Service
- Fast acq (IoT, mass market)
- Improved cold-start TTFF
- Decimeter accuracy
- Assistance/Long-term ephemeris
- **Robustness**

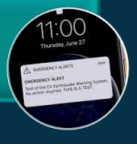
Timing Service
- Standalone
- Improved accuracy
- GST determination accuracy
- Time Service Monitoring
- **Robustness**

High Accuracy Service
- Improved convergence and accuracy
- Spare Data capacity
- **Robustness**

OS Authentication & SAS
- G1/G2 OS NMA
- G2 OS Range Authentication
- Encrypted signal for ranging (SAS)
- **Robustness**

SAR
- 2nd Generation Beacons
- Remote Beacon Activation
- Two way
- Improve RLS latency
- **Robustness**

Emergency Warning Service
- EWS msg dissemination
- Improve latency
- Improve reception probability
- **Robustness**



PRS

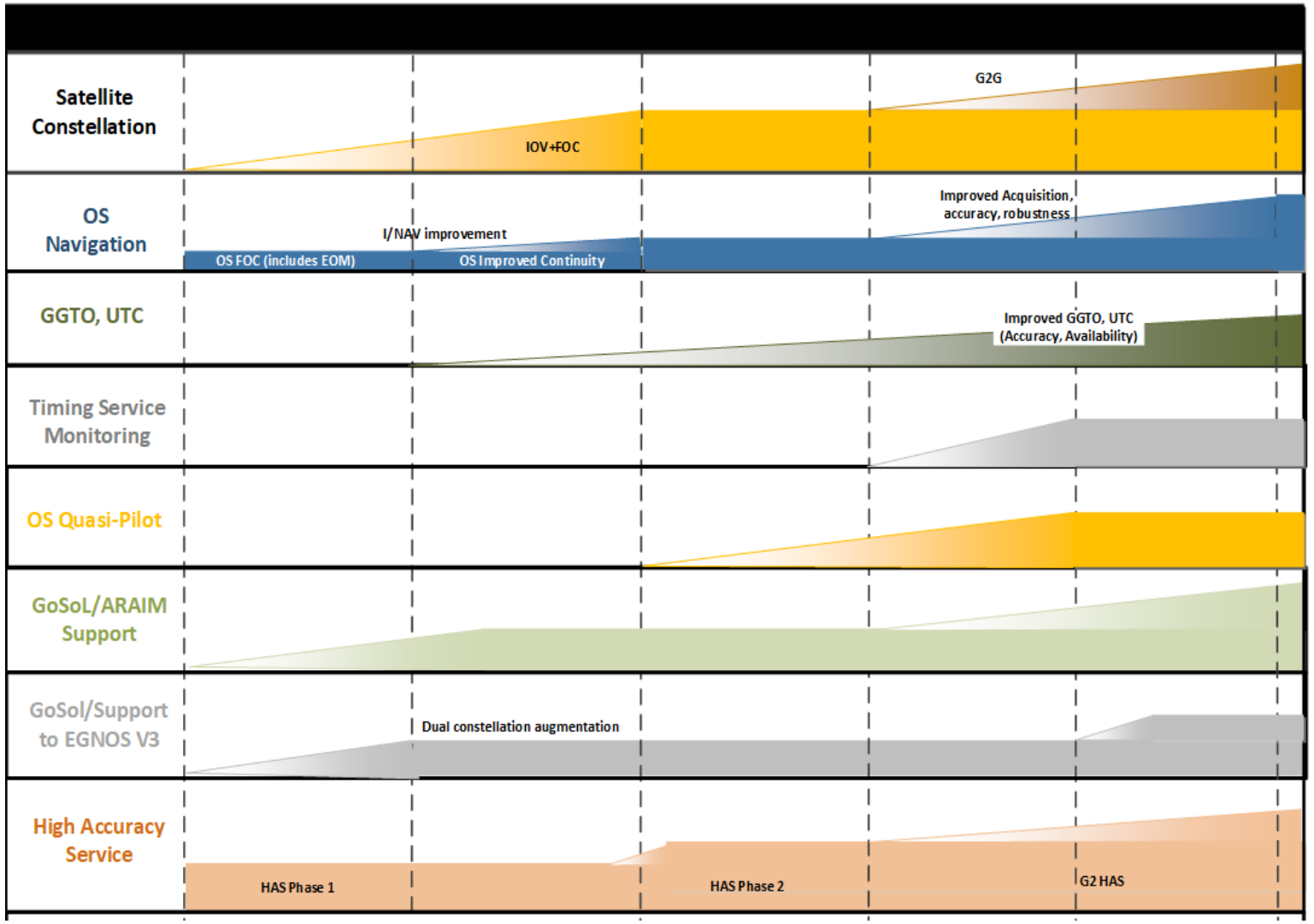
1 **Improved legacy PRS performance**

A-PRS/Robustness

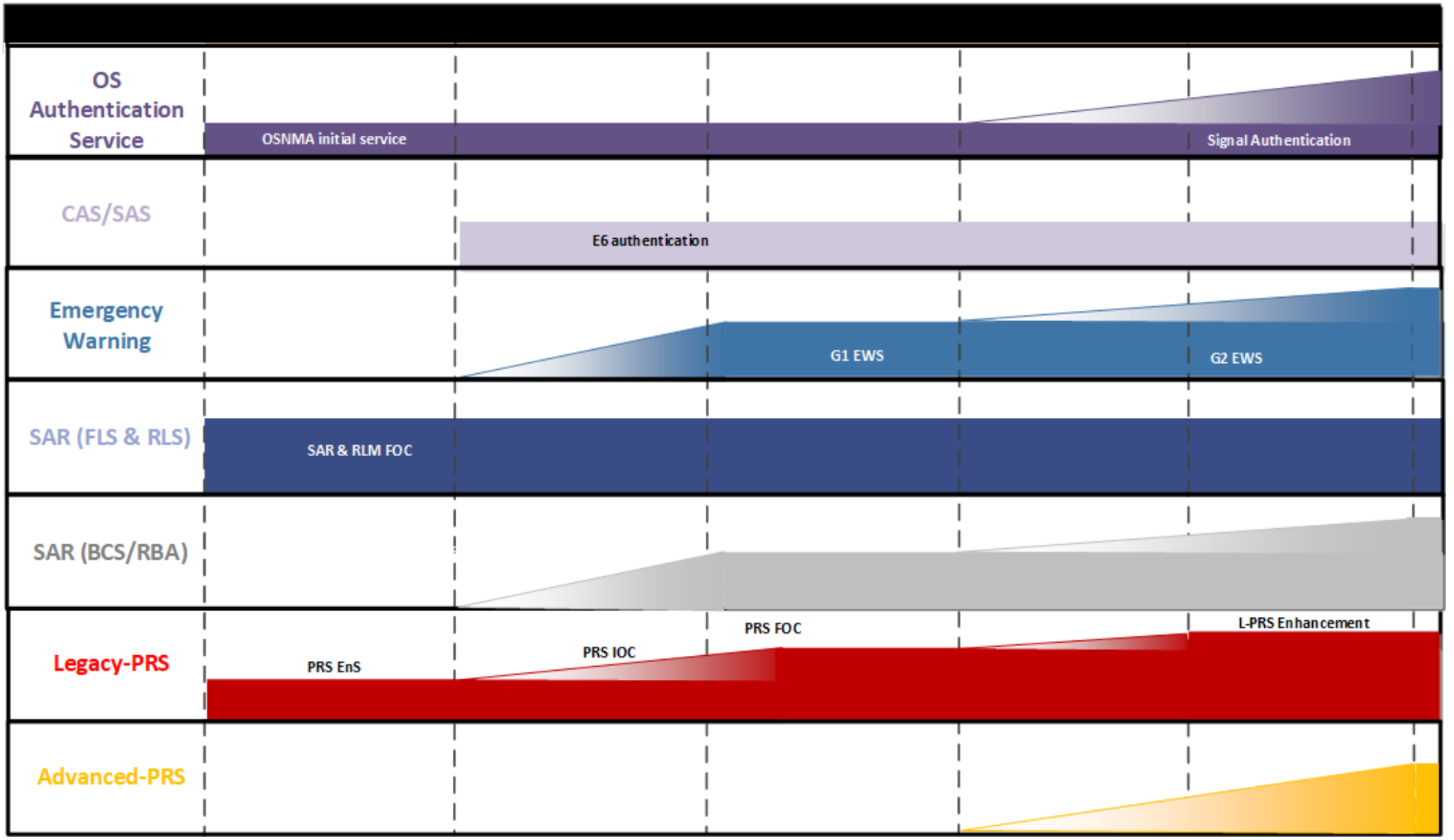
Support to SoL
- As-designed Support to EGNOS
- H-ARAIM
- Integrity Support Msg dissemination
- **Robustness**

Legacy Galileo Services Enhancement & New Services up to 2035 ongoing continuous consolidation thanks to the EC/EUSPA/ESA coordination.

G2G Future Services



G2G Future Services



G2G Final Operational Capability

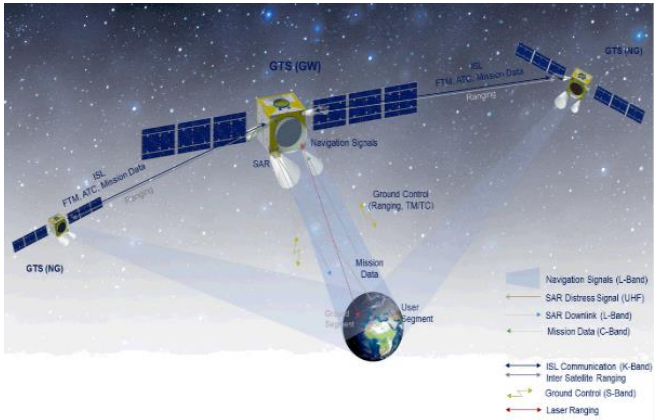
Improve connectivity and observability

Increase performance and service resilience

Two-way services

New Satellite & Ground Segment Technologies

2028-2035 Focus: G2 Satellites Batch#2 & G2G Ground Segment Final Operational Capability



Multilayer synergies with IRIS2, LEO-PNT & EGNOS systems & technologies.

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GPSTest

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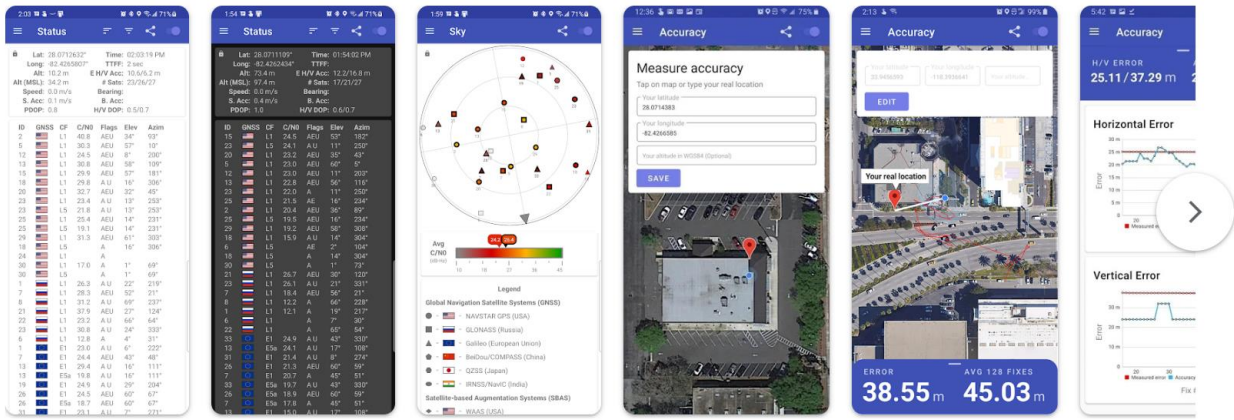

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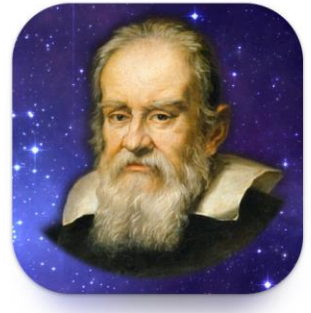

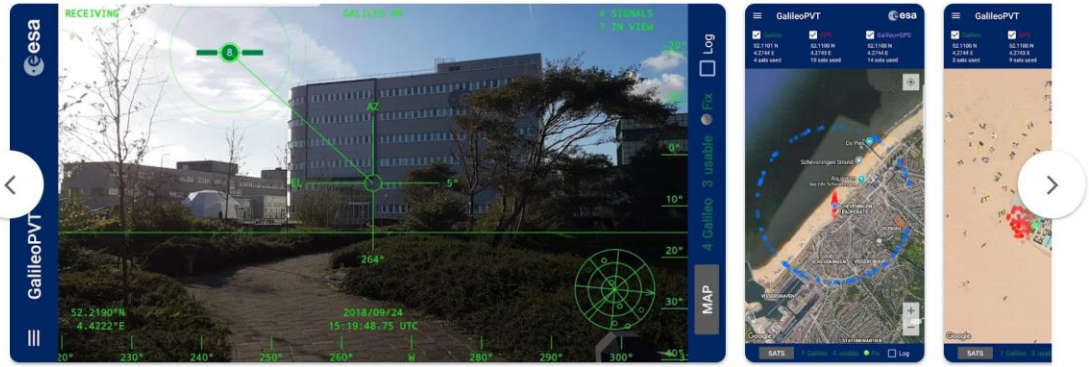

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