GALILEO – The European Satellite Navigation System

Applications of the GALILEO System

Status and Trends of the GALILEO deployment

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- Why will there be a new Satellite Navigation System, namely GALILEO?

- What is GALILEO?

- In which way is GALILEO different from GPS?

Overview

- **Introduction**
  - Motivation
  - Organisation
- **System architecture**
  - Overview
  - Space segment
  - Control segment
- **GALILEO services**
- **GALILEO Positioning accuracy**
- **GALILEO Status and Trends**

Motivation for GALILEO
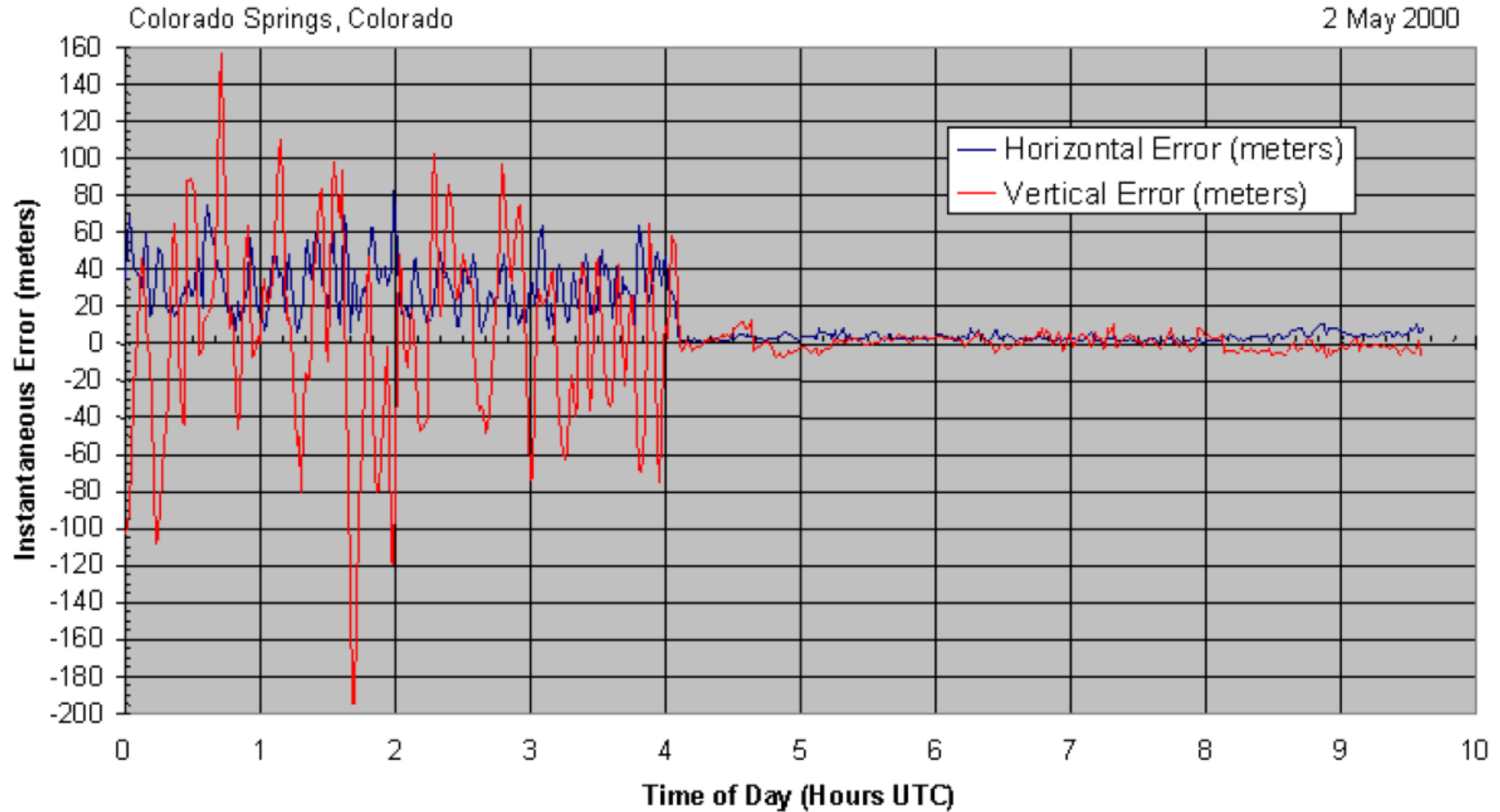
- **Global Positioning System (GPS)**
  - Develolped AND operated by the US Department of Defense
  - In full operation since 1992
  - **Main objective:** determination of **Position and Speed of arbitrary non-moving and moving objects for military use**.

- **GLObal NAvigation Satellite System (GLONASS):**
  - Mid 1970s: Decision by USSR Department of Defense to develop a global satellite navigation system.
  - Until 1997: 72 satellites launched
  - At most 21 satellites „active" at the same time.
  - # of active satellites decreased continuously over time (due to insufficient life time and problems with power transistors)
  - January 2009: 20 satellite „active".
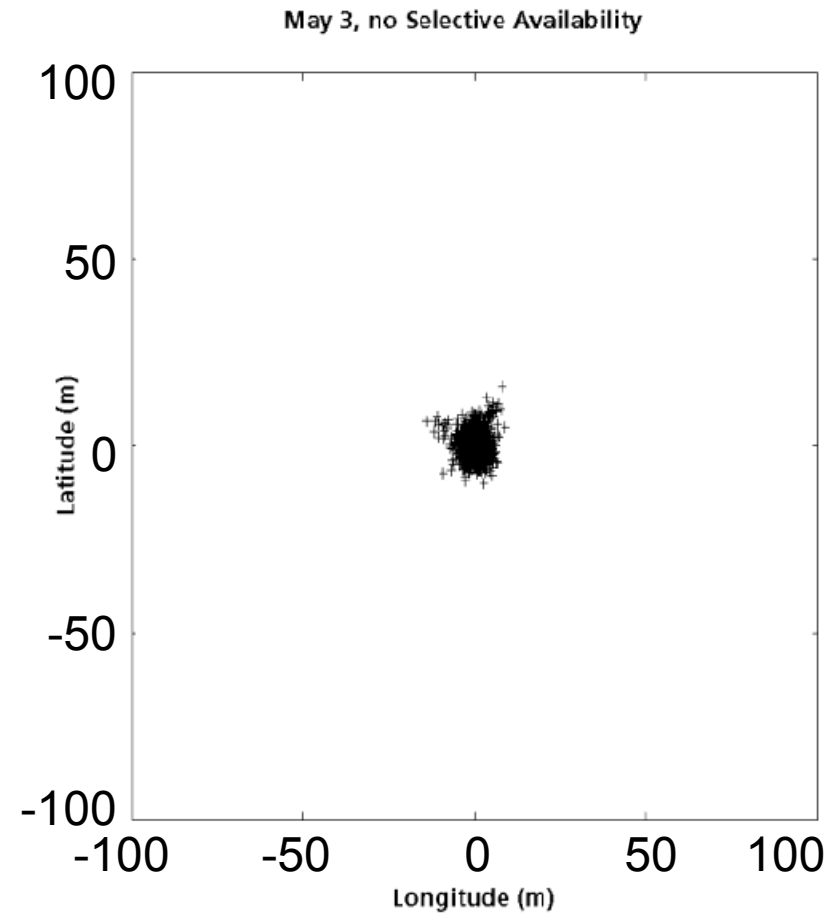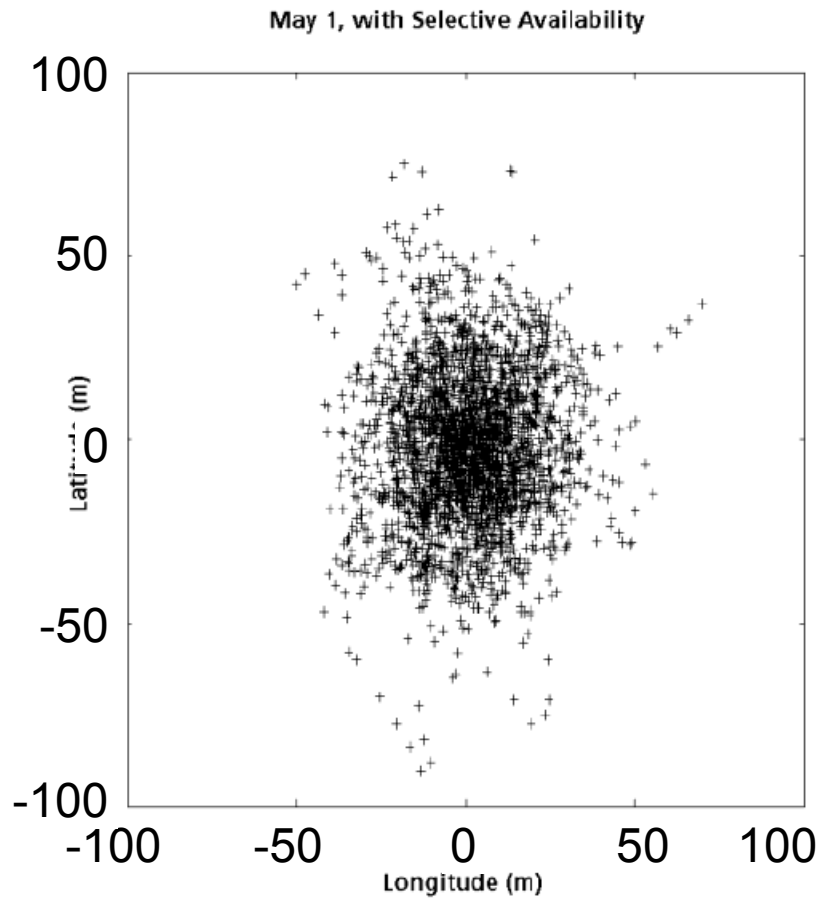 - **Primary use for military purposes (same as in GPS).**

Motivation for Galileo

- Positioning Accuracy improvement due to closedown of selective availability (SA) May 2nd, 2000

Motivation for Galileo

- Positioning Accuracy improvement due to closedown of selective availability (SA) May 2nd, 2000

May 1, with Selective Availability

May 3, no Selective Availability

Motivation for GALILEO

- **independence from USA**

- purely **CIVIL navigation system**.

- **compatibility with GPS → more redundancy and higher positioning precision**

- **several services**: 4 (possibly 5) different services

- **SAR (Search-and-Rescue-) function**, includ. **alarm confirmation**

- **integrity messages** to inform user immediately about malfunction of satellites/services

- **availability guarantee**

- build up **satellite navigation system Know-How**

- **creating jobs**

- **better coverage**

Source: J.-M. Zogg: GPS und GNSS: Grundlagen der Ortung und Navigation mit Satelliten, chapter 5
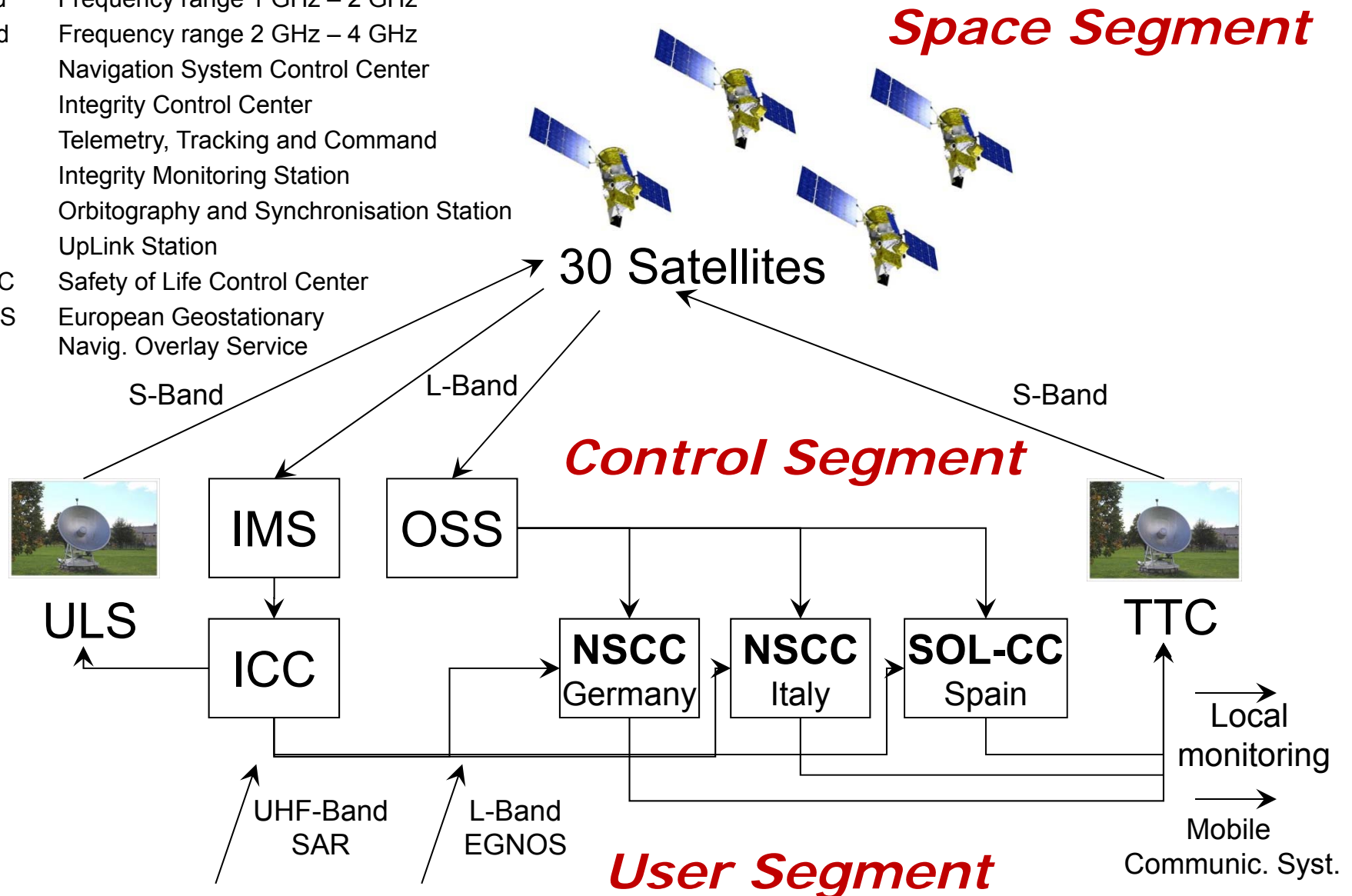
GALILEO Introduction - Organisation

- GALILEO developed and economically supported by 16 (out of 28) EU members.
  - In addition, the following countries committed contributions to Galileo:
    - China (technical development, 280 Million €)
    - India (Software Development)
    - Israel
    - Marokko
    - Saudi-Arabia
    - South Korea
    - Ukrain
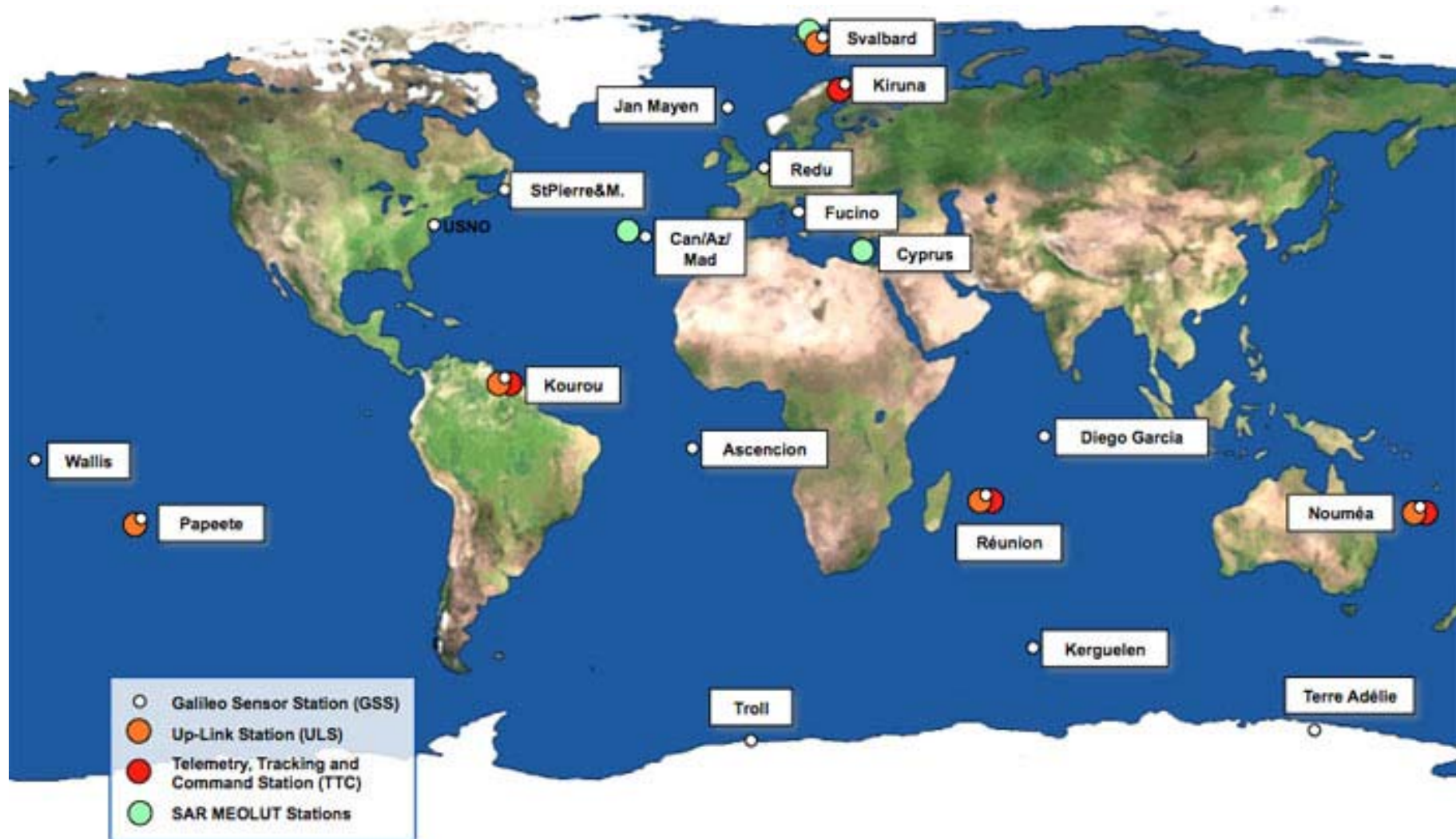   - Norway (Member of ESA)
    - Switzerland (Member of ESA)

Source: J.-M. Zogg: GPS und GNSS: Grundlagen der Ortung und Navigation mit Satelliten, chapter 5

GALILEO System architecture overview

L-Band — Frequency range 1 GHz – 2 GHz
S-Band — Frequency range 2 GHz – 4 GHz
NSCC — Navigation System Control Center
ICC — Integrity Control Center
TTC — Telemetry, Tracking and Command
IMS — Integrity Monitoring Station
OSS — Orbitography and Synchronisation Station
ULS — UpLink Station
SoL-CC — Safety of Life Control Center
EGNOS — European Geostationary Navig. Overlay Service

Space Segment
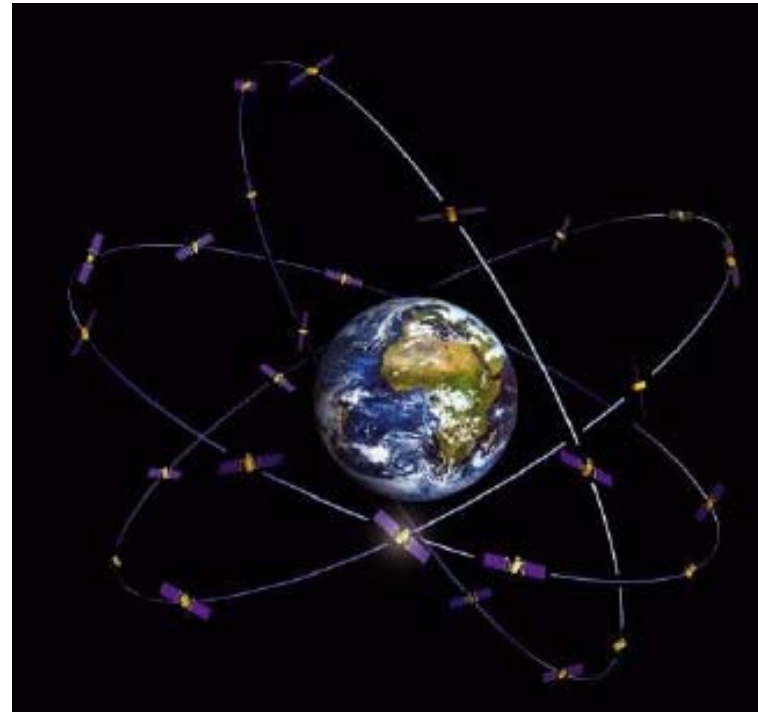
30 Satellites

S-Band   L-Band   S-Band

Control Segment

ULS   IMS   OSS   TTC

ICC   **NSCC** Germany   **NSCC** Italy   **SOL-CC** Spain

UHF-Band SAR   L-Band EGNOS

Local monitoring

Mobile Communic. Syst.

User Segment

GALILEO System architecture - ground segment

Galileo ground segment world map showing station locations:

Svalbard, Kiruna, Jan Mayen, Redu, Fucino, Cyprus, StPierre&M., USNO, Can/Az/Mad, Kourou, Wallis, Papeete, Ascencion, Réunion, Diego Garcia, Nouméa, Kerguelen, Troll, Terre Adélie

Legend:
- ○ Galileo Sensor Station (GSS)
- ● Up-Link Station (ULS)
- ● Telemetry, Tracking and Command Station (TTC)
- ● SAR MEOLUT Stations

GALILEO System architecture – Space Segment

- ## Space Segment (starting 2015):

  - Initial constellation: 18 satellites

  - **After 2020** (Full Operational Capability): **30 satellites (24 satellites needed for operation, 6 as „backup")**

  - Circular orbits

  - Satellite **height above earth: 23.616 km (orbit radius: 29.933 km), speed v□ 13.355 km/h**

  - **3 orbit planes,** orbit planes differ by 120° in longitude

  - **Inclination: 56°**

  - Orbital period: 14 h and 5 min.

Source: J.-M. Zogg: GPS und GNSS: Grundlagen der Ortung und Navigation mit Satelliten, chapter 5

GALILEO services

Service	Naming	Abbrev.	Comment
1	Open Service	OS	
2	Commercial Service	CS	
3	Safety-of-Life Service	SoL	
4	Public Regulated Service	PRS	
5	Save-and-Rescue Service	SAR	Outside GALILEO signal structure

Source: J.-M. Zogg: GPS und GNSS: Grundlagen der Ortung und Navigation mit Satelliten, chapter 5

GALILEO services

- **Service 1: Open service:**
  - Availabe free of charge for the public
  - Provides positioning and timing information
  - Allows for 2- and 3-dimensional positioning
  - For applications with lower precision requirements, GPS and GALILEO signals are the same, hence navigation system receivers may combine GPS and GALILEO signals. → improved reception.
  - No integrity messages
  - No availability guarantee

Source: J.-M. Zogg: GPS und GNSS: Grundlagen der Ortung und Navigation mit Satelliten, chapter 5

GALILEO services

- **Service 2: Commercial Service**
  - Planned for **applications with increased (precision) requirements**
  - Users are being charged for use of these applications
  - Signals of these services are encrypted
  - Services with
    - high data rates
    - Availability guarantee
    - Exact time based services
    - Offering of modells for ionospheric delay
    - Provisioning of local differential correction signals for high precision positioning.
    - Access control by access protection codes

Source: J.-M. Zogg: GPS und GNSS: Grundlagen der Ortung und Navigation mit Satelliten, chapter 5

GALILEO services

- **Service 3: Safety critical service – Safety of Life, SoL**
  - Open access (as in Open Service)
  - Applications planned for satety relevant traffic use cases
  - Provides the following integrity information to avoid safety critical and life threatening situations
    - **Alarm within 6 seconds, if horizontal distance error > 12m and/or if vertical distance error > 20 m**
    - Alarm security: 99,5%
    - Integrity risk < 3.5 $\cdot$ 10^{-7}
  - Used for air- (e.g. aircraft landings), railroad- and marine-traffic
  - Can only be used by certified 2-frequency band receivers

Source: J.-M. Zogg: GPS und GNSS: Grundlagen der Ortung und Navigation mit Satelliten, chapter 5

GALILEO services

- ## Service 4: Public Regulated Service, PRS
  - GALILEO is a civil system (but may used by military organisations as well).
  - PRS is a reserved service for organisations like police, fire departments, frontier defense, ….
  - Usage only via access control
  - Encrypted services
  - Service must have „all-time-availability".

Source: J.-M. Zogg: GPS und GNSS: Grundlagen der Ortung und Navigation mit Satelliten, chapter 5
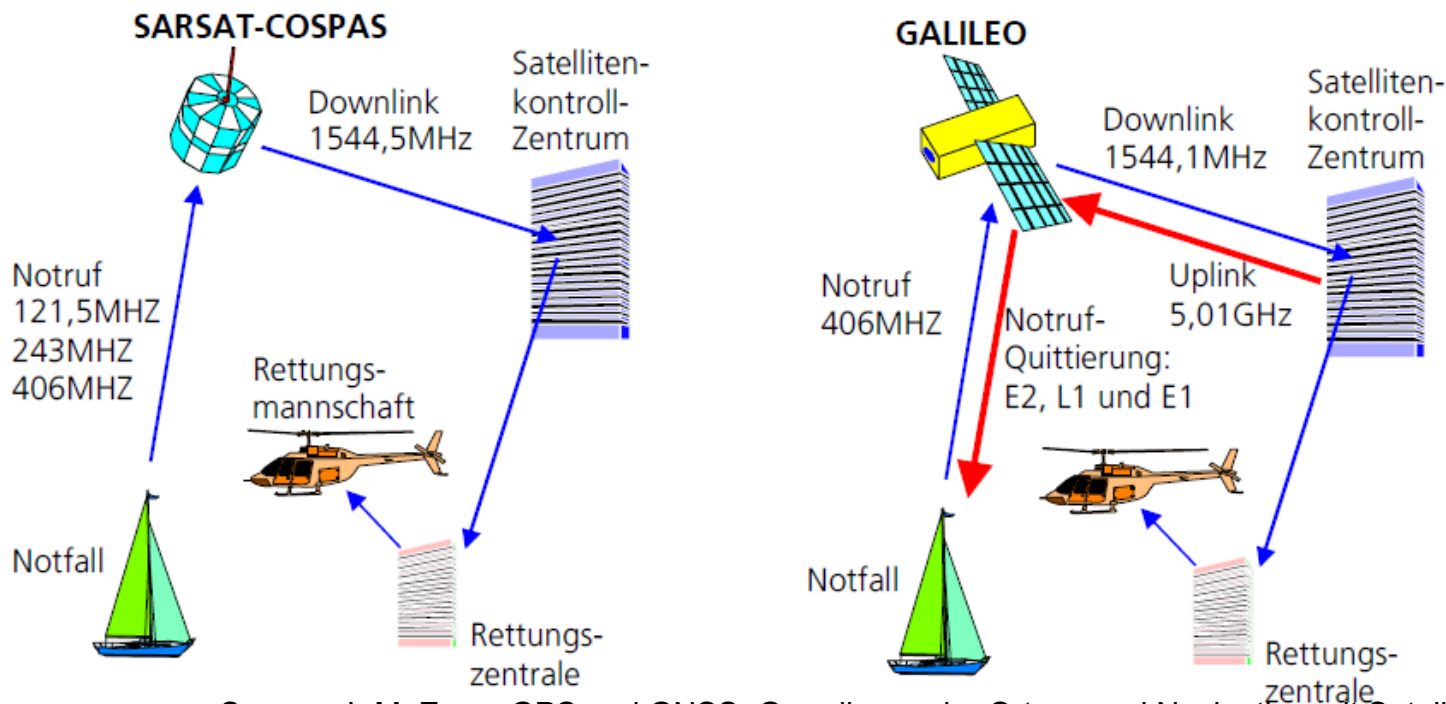
GALILEO services

- **Service 5: Search-and-Rescue (SAR)**
  - Service for humanity use, i.e. to search for individual persons or vehicles, equipped with an active „emergency transmitter".
  - Combination of emergency transmitters and satellites allows positioning of individuals, e.g. in case of avanlaches
  - May be used in case of marine, air or land emergency cases.
  - In 1970s USSR and France developed the so called SARSAT (Search and Rescue Satellite-Aided Tracking)-system, based on 6 Low-Earth-Obit-satellites and 5 GEO-(stationary)-satellites.
  - GALILEO SAR-service shall improve SARSAT:
    - Detection by several satellites, i.e. by COSPAS-SARSAT system and GALILEO, LEO- and GEO-satellites.
    - Reception of emergency calls from any point on Earth in realtime (low delay, up to now: delay in average 1 hour)
    - Precise positioning of emergency call-origin (a few meters, up to now: 5 km!)

Source: J.-M. Zogg: GPS und GNSS: Grundlagen der Ortung und Navigation mit Satelliten, chapter 5

GALILEO services

- **Service 5: Search-and-Rescue (SAR) (continued):**
  - GALILEO SAR will provide a feedback loop (confirmation message) from SAR-provider to emergency radio beacon. This shall:
    - Support rescue activities
    - Reduce the number of false alarms

Source: J.-M. Zogg: GPS und GNSS: Grundlagen der Ortung und Navigation mit Satelliten, chapter 5

Positioning Accuracy of GALILEO

Service	Receiver Type	Horizontal positioning accuracy	Vertical positioning accuracy
Open Service	Single Frequency Receiver	15 m	35 m
Open Service	Double Frequency Receiver	4 m	8 m
Commercial Service	Double Frequency Receiver	< 1 m	< 1 m
Public Regulated Service	Single Frequency Receiver	6,5 m	12 m
Safety of Life Service	Double Frequency Receiver	4 …6 m	4 …6 m

Source: J.-M. Zogg: GPS und GNSS: Grundlagen der Ortung und Navigation mit Satelliten, chapter 5
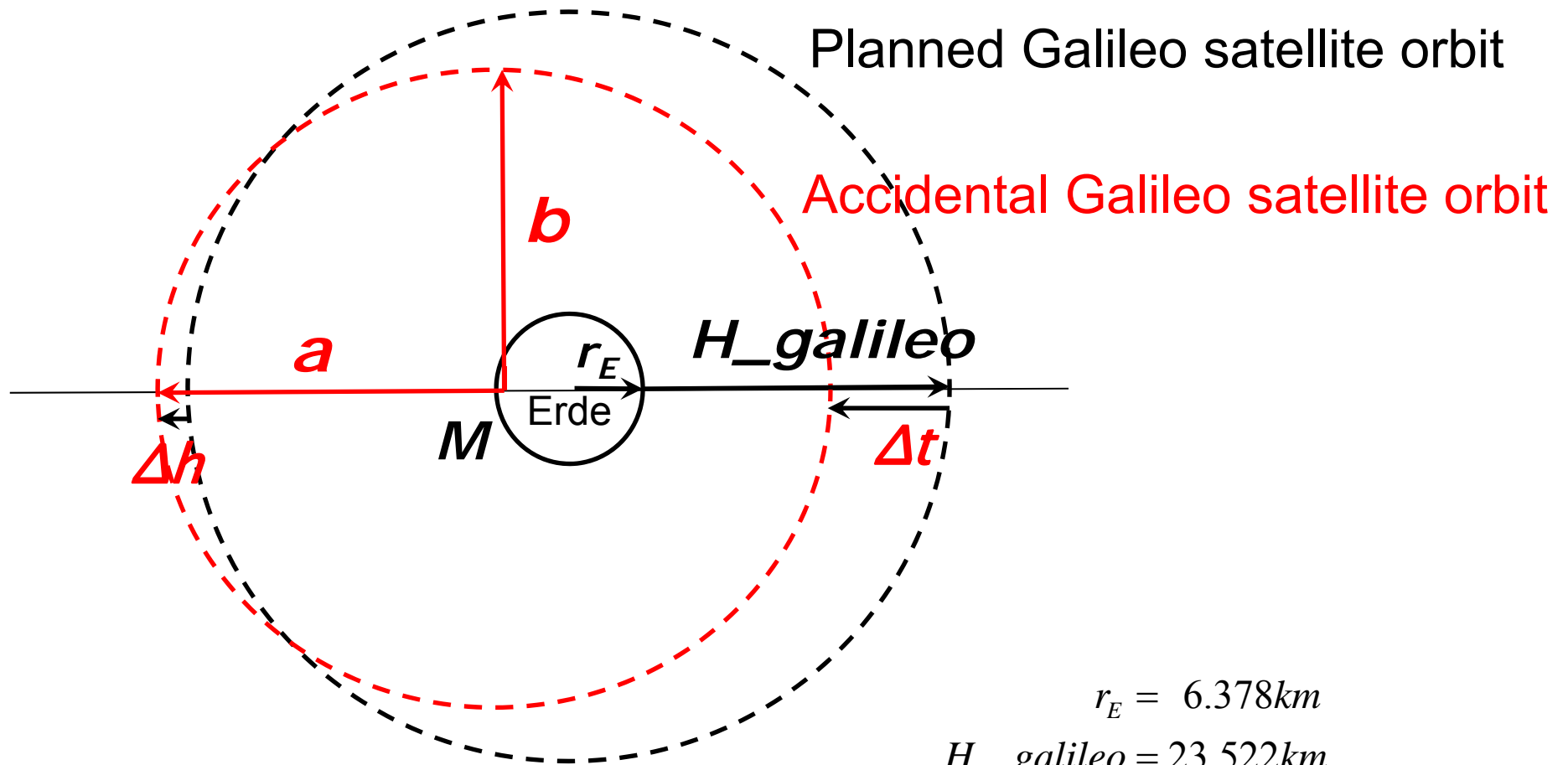
GALILEO Services

- [Galileo Services - ESA-Video](#)

Source: European Space Agency, ESA

GALILEO – Status and Trends

- **October 21st, 2011:** GALILEO satellites 1 and 2 launched

- **October 12th, 2012:** GALILEO satellites 3 and 4 launched – 1st system verification possible.

- **March 12th, 2013:** In-Orbit Validation successful, 1st GALILEO only position

- **August 21st, 2014:**
  - GALILEO satellites 5 and 6 launched
  - 2 satellites moving in wrong orbit. Correction possibilities unclear.

- **October 28th, 2014:**
  - Reason: Hydrazin-pipe temporarily frozen at start of Sojus carrier-rocket → wrong movement/position of carrier rocket → wrong orbit of GALILEO satellites
    - Satellites moving on elliptical instead of circular orbit, partly 2.700 km too high, partly 9.500 km too low.

Galileo-satellites with correct and erroneous orbit

Planned Galileo satellite orbit

Accidental Galileo satellite orbit

b

a

r_E

$H\_galileo$

Erde

M

Δh

Δt

$r_E = 6.378 km$

$H\_galileo = 23.522 km$

$\Delta t = 9.500 km$

$\Delta h = 2.700 km$

- **GALILEO satellites recovered - ESA Video**

Source: European Space Agency, ESA

GALILEO – Status and Trends

- **November 2014:** GALILEO satellite 5 reaches corrected orbit

- **March 19th, 2015:** GALILEO satellite 6 reaches corrected orbit (14 maneuvers necessary over approx. 2 months).

- **March 27th, 2015:** GALILEO satellites 7 and 8 launched.

- **September 11th, 2015:**
  - GALILEO satellites 9 („Alba") and 10 („Oriana") successfully launched in 23.500 km height above earth after 3 hours and 48 minutes flight time.

- **Q4 2015:** Planned launch of 2 additional GALILEO satellites.

- **2016:** Planned launch of 4 addtional GALILEO satellites with Ariane-5-carrier rocket.

- **By 2020:**
  - 30 GALILEO satellites shall be launched.

Thank you very much for your attention!

References

1. Jean-Marie Zogg: "GPS und GNSS: Grundlagen der Ortung und Navigation mit Satelliten", May 2014, available at: http://zogg-jm.ch/weitere_publikationen.html

2. Werner Mansfeld: „Satellitenortung und Navigation: Grundlagen, Wirkungsweise und Anwendung globaler Satellitennavigationssysteme", Vieweg-Teubner Verlag, 2009

3. Spiegel-Online arcticles on GALILEO: several arcticles with publication data ranging from 2011 until 2015.

4. European Space Agency (ESA): „Space in Videos" - http://www.esa.int/spaceinvideos/content/search?SearchText=galileo&SearchButton=Go