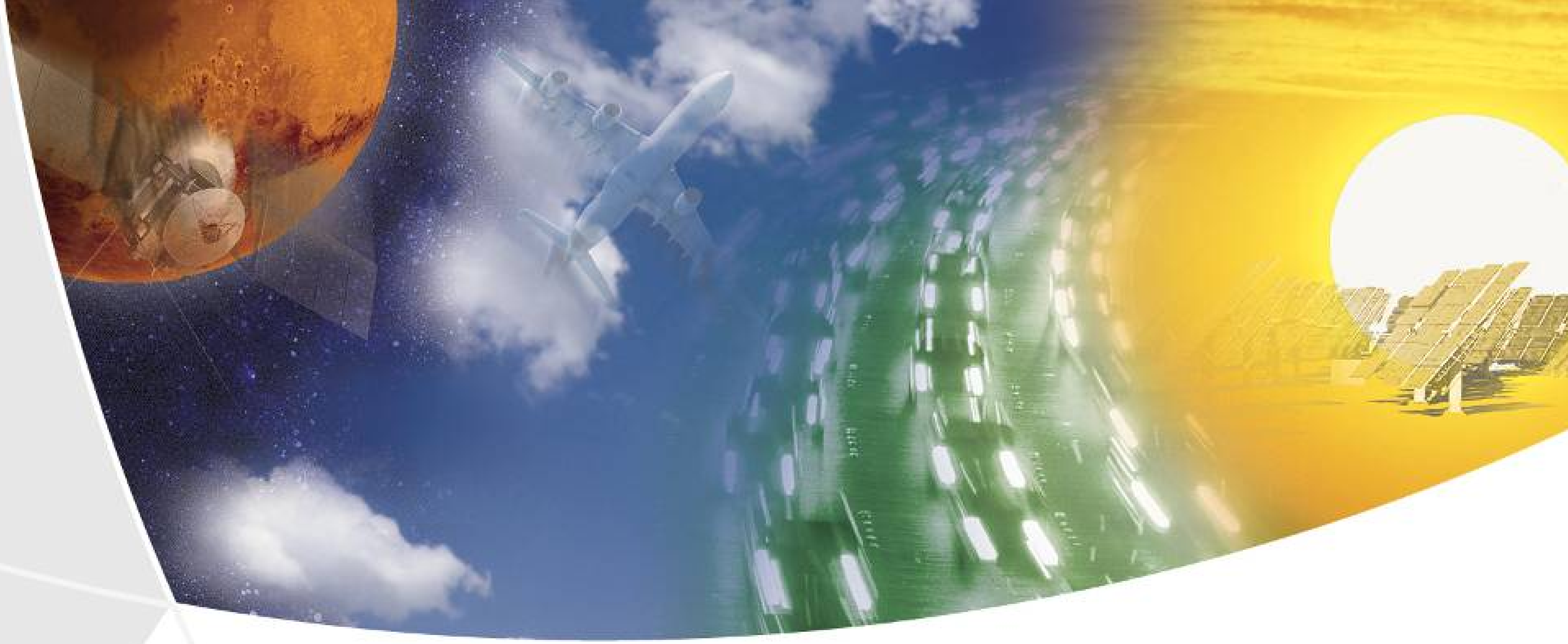


On Galileo

Uwe-Carsten Fiebig
German Aerospace Centre (DLR)

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Principles of satellite navigation

What is navigation?

- Science of getting a craft / person from one place to another
- Everybody uses navigation skills which require the use of
  - Eyes to detect landmarks, common sense
- More accurate systems are based on clocks, odometer and electronic signals etc.

Early development of space-based systems:

- *Transit* (U.S. Navy); operational in 1964
  - Position fix only every 30 to 110 minutes depending on the location.
  - Suitable only for ships, but not for aircraft and other high-dynamic users.
- *Tsikada* (Russian system)

Development of global satellite based navigation systems (GNSS) in the 70s/80s:

- American ***NAVSTAR GPS*** (NAVigation System using Time And Ranging - Global Positioning System) and
- Russian ***GLONASS*** (Global Navigation Satellite System)
- European ***GALILEO*** (from 2011)

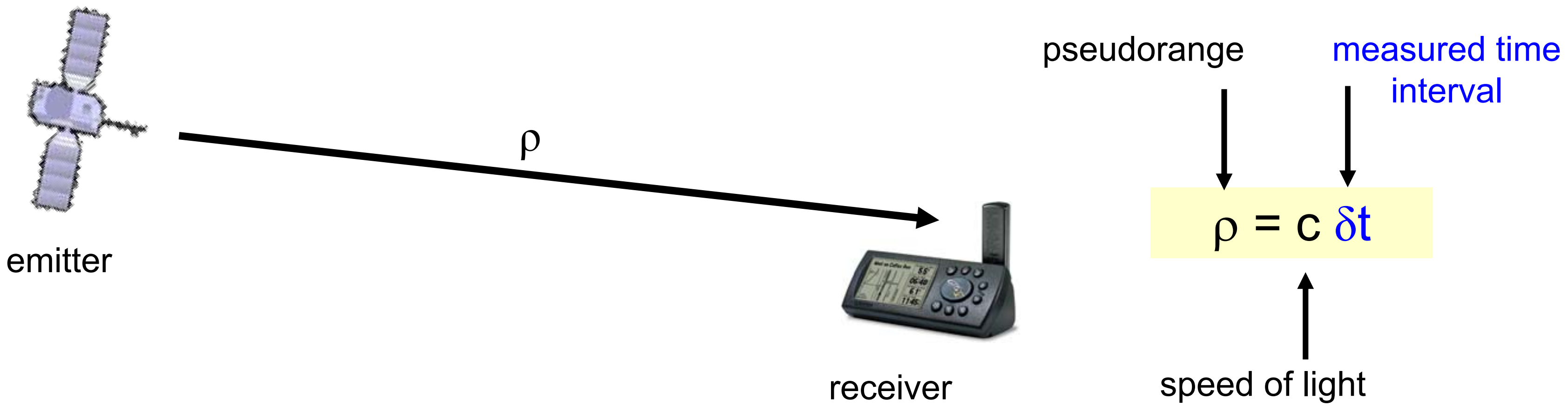
Principles of satellite navigation

Fundamentals of TOA based systems

- Satellite positioning systems are based on a technique called TOA (**Time of Arrival**)

Principle of TOA

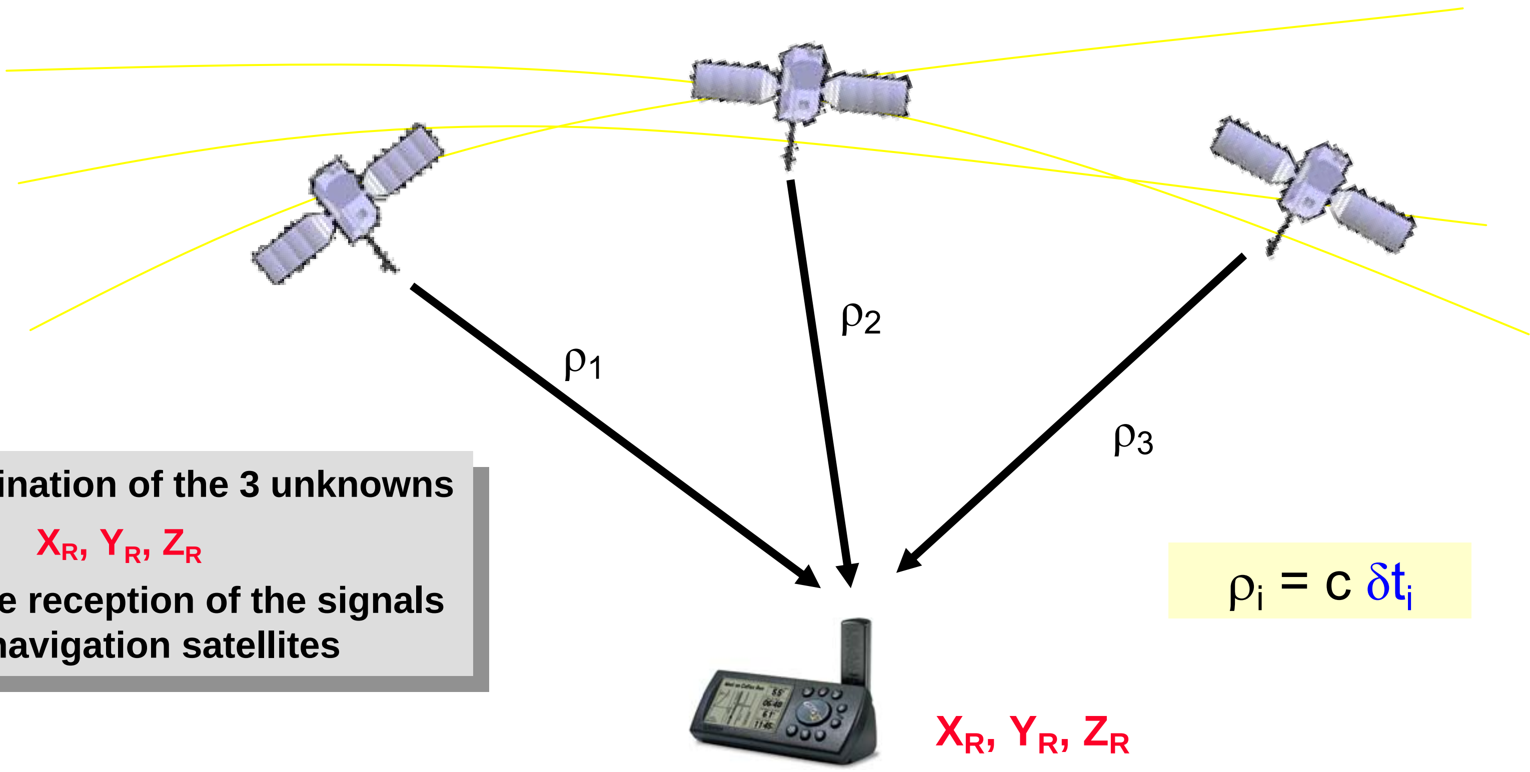
- Measure the time it takes for a signal transmitted by an emitter at a known location to reach a user receiver: This time interval is the signal propagation time ***δt***
  - Receiver must know when the signal left the emitter
  - Receiver must know the position of the emitter
- ***δt*** is multiplied by the speed of light *c* resulting in the emitter-to-receiver distance ρ



Principles of satellite navigation

Principle of TOA positioning in SatNav systems

- Range measurements to at least 3 satellites have to be carried out simultaneously.



The determination of the 3 unknowns

X_R, Y_R, Z_R

requires the reception of the signals of 3 navigation satellites

$$\rho_i = c\,\delta t_i$$

Principles of satellite navigation

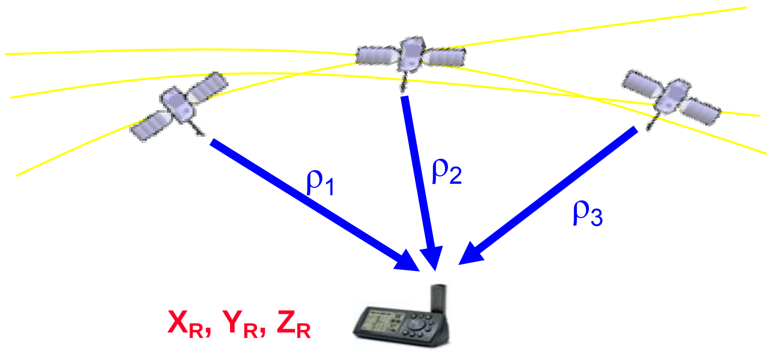
Principle of TOA positioning in SatNav systems

- Navigation equation has to be solved to get the user's position

$$c \cdot \delta t_1 = \rho_1 = \sqrt{\left[X_{SAT-1} - X_R\right]^2 + \left[Y_{SAT-1} - Y_R\right]^2 + \left[Z_{SAT-1} - Z_R\right]^2}$$

$$c \cdot \delta t_2 = \rho_2 = \sqrt{\left[X_{SAT-2} - X_R\right]^2 + \left[Y_{SAT-2} - Y_R\right]^2 + \left[Z_{SAT-2} - Z_R\right]^2}$$

$$c \cdot \delta t_3 = \rho_3 = \sqrt{\left[X_{SAT-3} - X_R\right]^2 + \left[Y_{SAT-3} - Y_R\right]^2 + \left[Z_{SAT-3} - Z_R\right]^2}$$



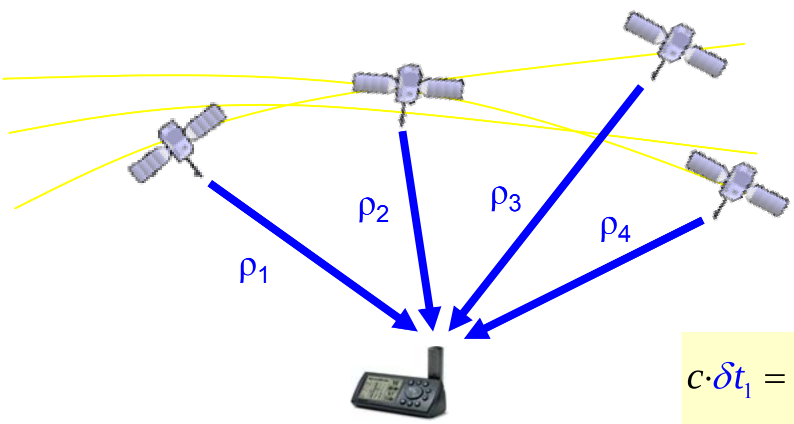
Is it possible to synchronise the receiver clock to the clocks of the satellites?

- A time uncertainty of 10 ns translates to an uncertainty in distance of 3 m (in 1 µs the signal travels 300 m)
- It is impossible today to synchronise the clocks of receiver **and** satellites
- Hence, the receiver's clock is offset with respect to the satellites' clocks

Principles of satellite navigation

Principle of TOA positioning in SatNav systems

- Simultaneous reception of the signals from 4 satellites is required
  - Measurement of the propagation delays of 4 signals: $\delta t_1, \delta t_2, \delta t_3, \delta t_4$
  - Determination of 4 „pseudo ranges“: $\rho_1, \rho_2, \rho_3, \rho_4$



Determination of the 3 unknowns of the location and the receiver's clock offset

$X_R, Y_R, Z_R, \delta T_R$

Navigation equation

$$c\cdot\delta t_1 = \rho_1 = \sqrt{\left[X_{SAT-1} - X_R\right]^2 + \left[Y_{SAT-1} - Y_R\right]^2 + \left[Z_{SAT-1} - Z_R\right]^2} + c\delta T_R$$

$$c\cdot\delta t_2 = \rho_2 = \sqrt{\left[X_{SAT-2} - X_R\right]^2 + \left[Y_{SAT-2} - Y_R\right]^2 + \left[Z_{SAT-2} - Z_R\right]^2} + c\delta T_R$$

$$c\cdot\delta t_3 = \rho_3 = \sqrt{\left[X_{SAT-3} - X_R\right]^2 + \left[Y_{SAT-3} - Y_R\right]^2 + \left[Z_{SAT-3} - Z_R\right]^2} + c\delta T_R$$

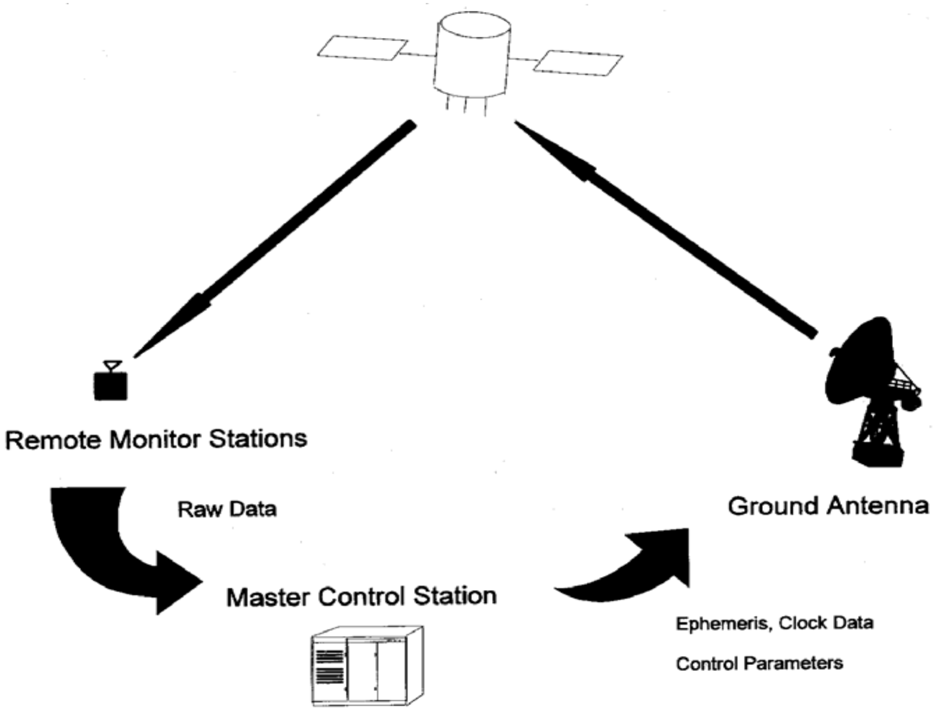
$$c\cdot\delta t_4 = \rho_4 = \sqrt{\left[X_{SAT-4} - X_R\right]^2 + \left[Y_{SAT-4} - Y_R\right]^2 + \left[Z_{SAT-4} - Z_R\right]^2} + c\delta T_R$$

Operational control segment

Tasks:

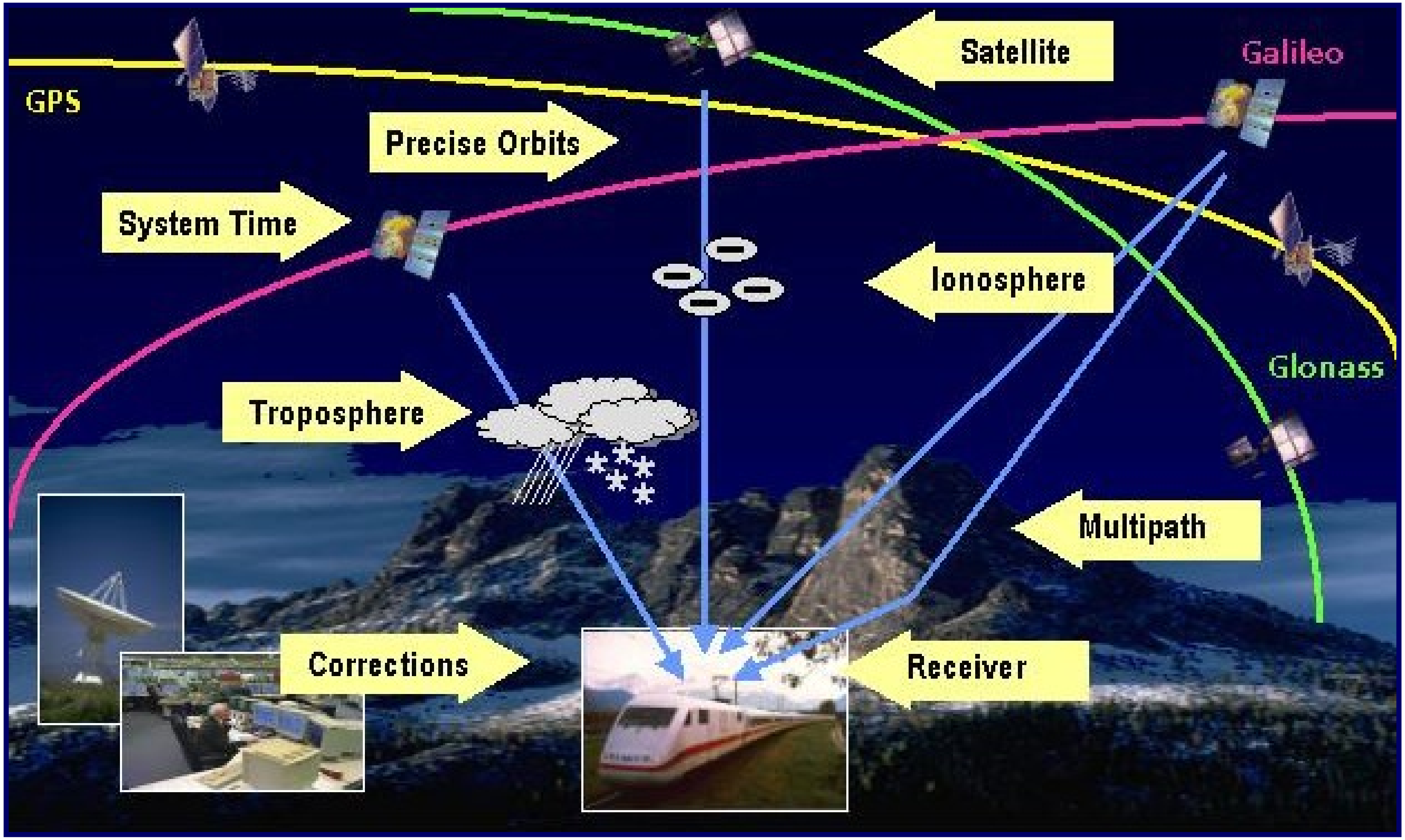
- Maintaining the satellites and their proper functioning
  - Station keeping: Maintaining the satellites in their proper orbital position.
  - Monitoring of satellite solar arrays, battery power levels, propellant levels etc..
  - Updating each satellite's clock, ephemeris and other parameters as needed.

    Ephemeris data have to be a precise fit to the satellite orbits and are valid only for 4 to 6 hours.



Source: E.D. Kaplan: ***Understanding GPS, Principles and Applications***, **Artech House, Boston, 1996.**

Overview of error sources



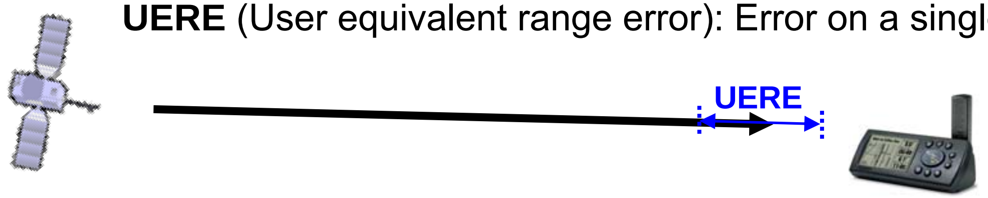
Error budget

Segment	Error source	1σ error [m]
Space	Satellite clock stability	**3.0**
	Predictability of satellite perturbations	1.0
	Selective availability	--
	Other (thermal radiation, etc.)	0.5
Control	Ephemeris prediction error	**4.2**
	Other (thruster performance, etc.)	0.9
User	Ionospheric delay	**5.0**
	Tropospheric delay	1.5
	Receiver noise and resolution	1.5
	Multipath	2.5
	Other (interchannel bias, etc.)	0.5
UERE	**Total (rms)**	**8.0**

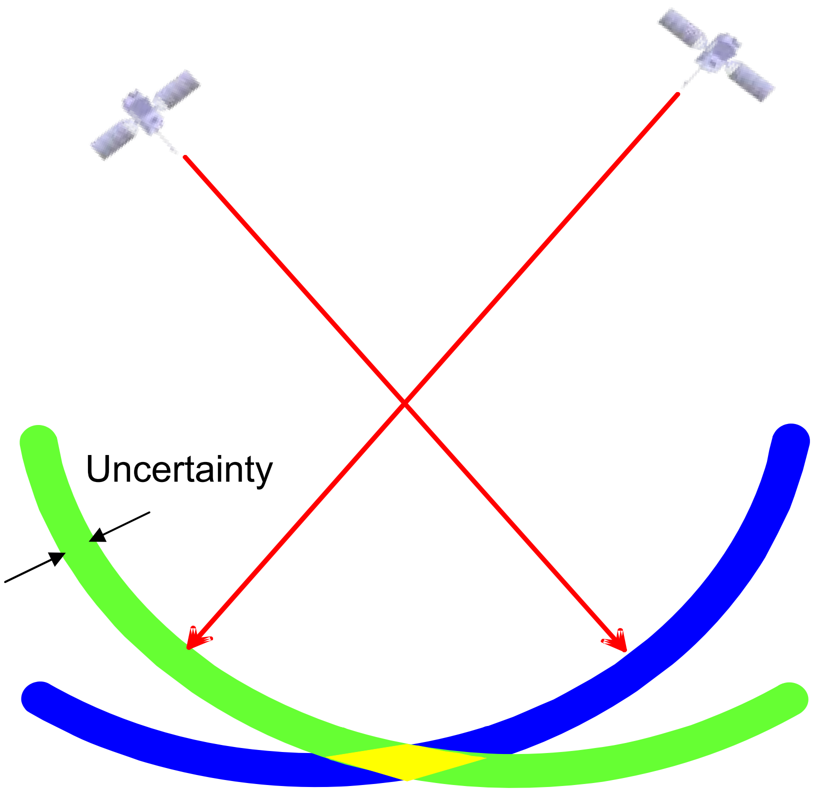
Today's GPS error budget

Galileo and new GPS make it better

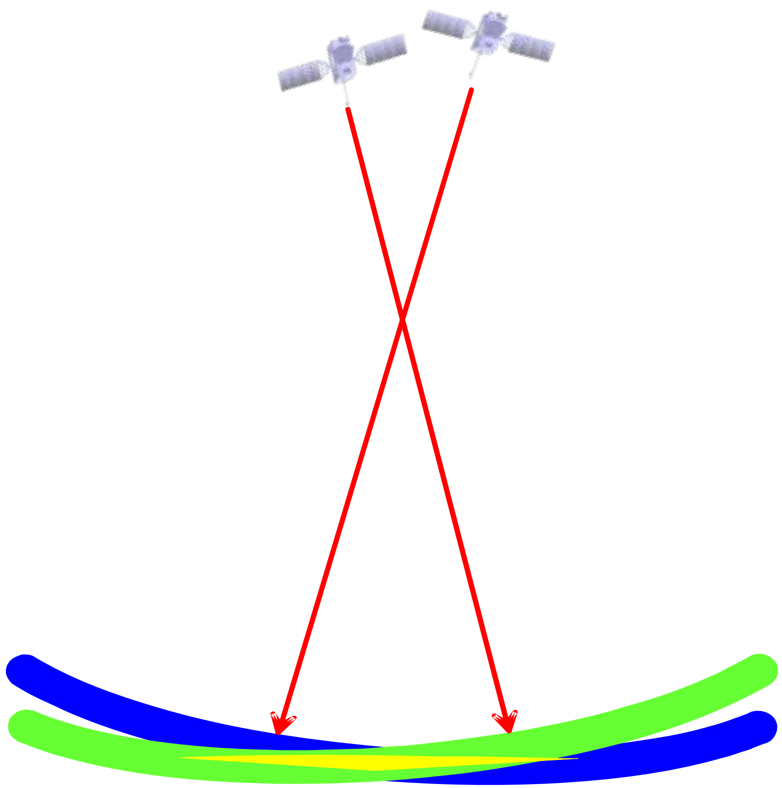
UERE (User equivalent range error): Error on a single pseudorange, not a the position!



Dilution of precision (DOP)



Good DOP value



Bad DOP value

Europe builds Galileo

- The increasing dependency of economics on global satellite navigation is visible in many domains
- GPS has become an important technological and economic factor
- However, GPS is a military system under control of the DoD
- Europe decided to develop, deploy and operate a satellite navigation system on its own

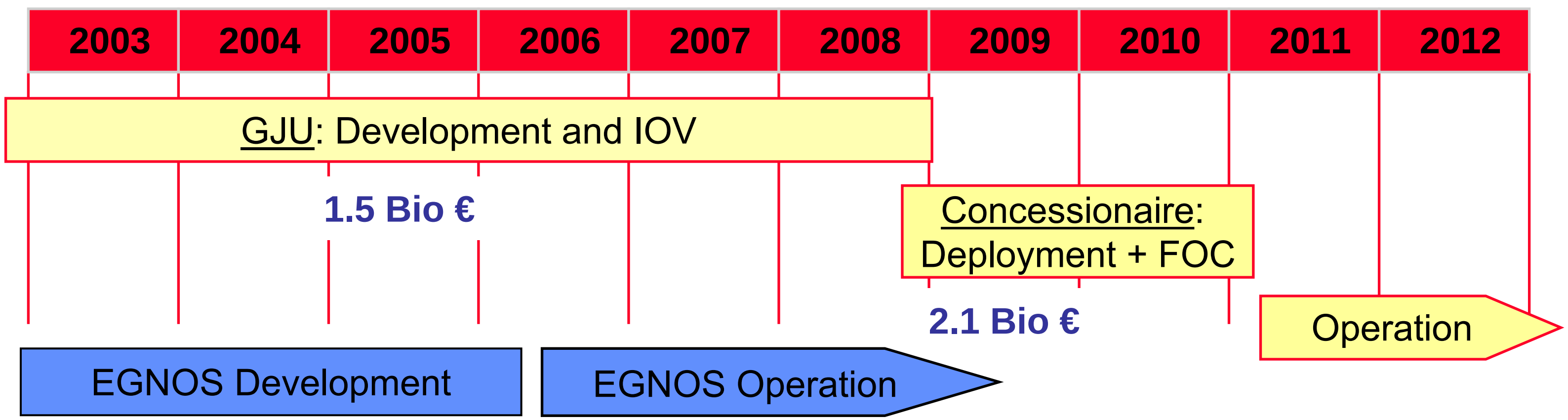
- Europe decides to build up its own satellite navigation system being **independent**, **compatible** and **complementary** to GPS

- Goal is to provide even better performance and additional functionality without increasing receiver costs:
  - Galileo provides integrity information and service guarantees
  - Galileo transmits navigation signal on at least 2 frequency
  - Larger transmit power enables better reception
  - Hybrid receivers (GPS & Galileo) can use twice the number of satellites of a single system

Europe builds Galileo

- First steps
  - Dec. 1999: ESA and EU decide to develop Galileo
  - May 26, 2003: Financing finalized

- Public Private Partnership

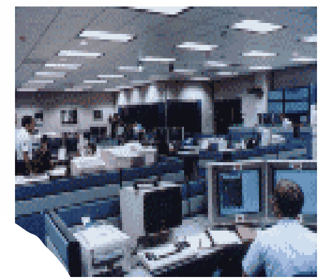


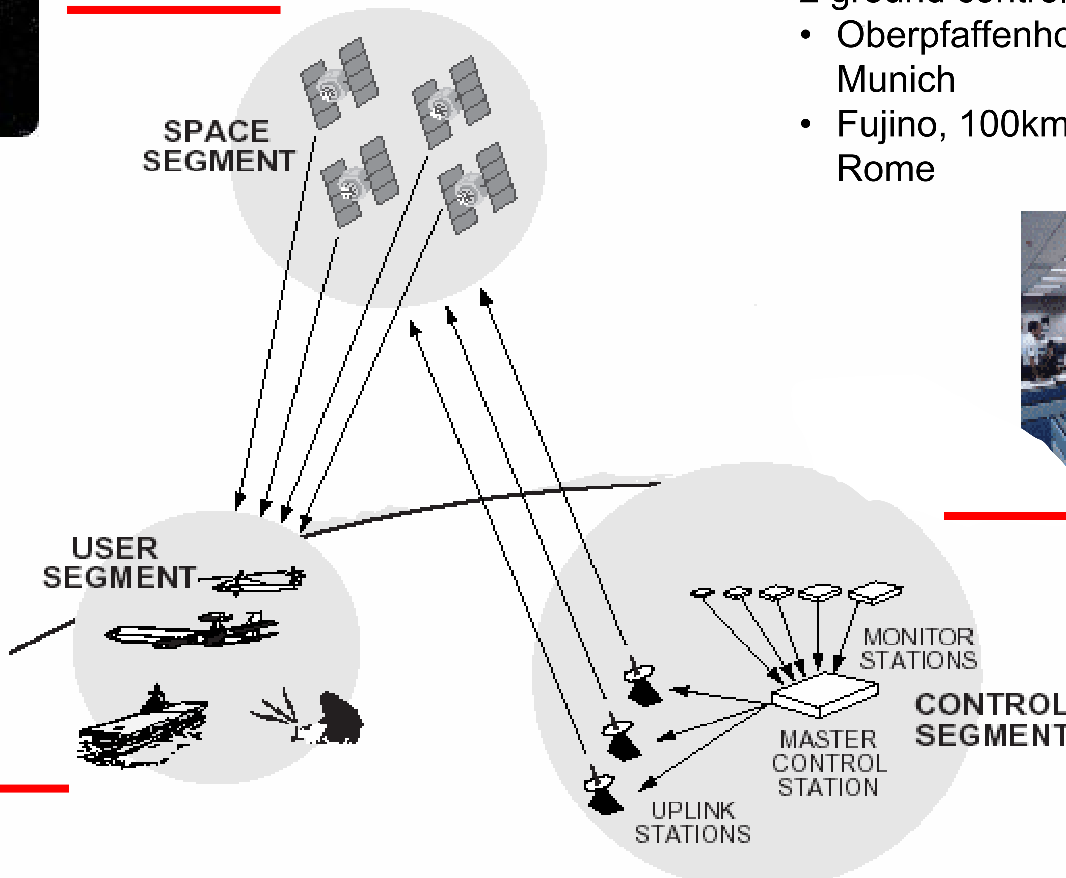
- Concessionaire, negotiations ongoing

Galileo system

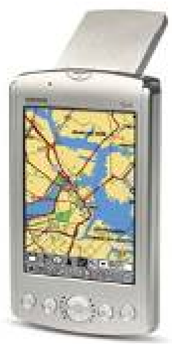
30 satellites

2 ground control centres:
- Oberpfaffenhofen, near Munich
- Fujino, 100km from Rome





services

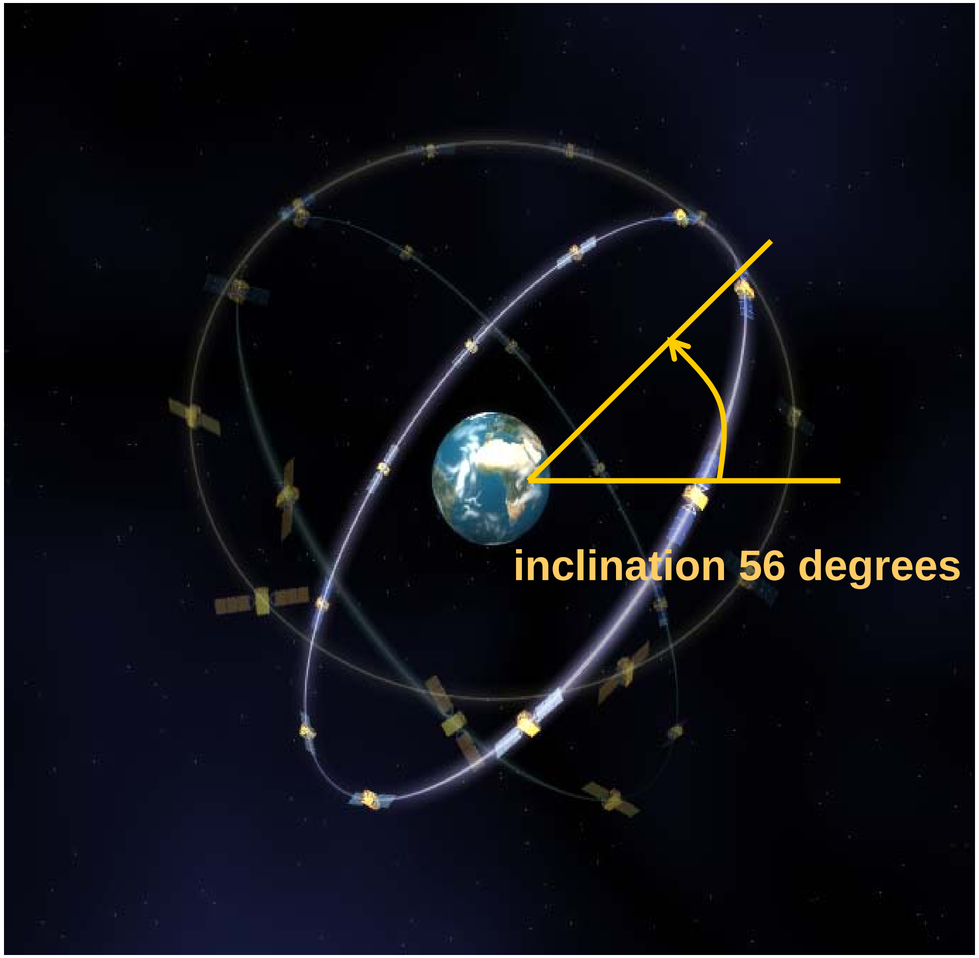


Galileo satellite constellation

Galileo satellite constellation

- 27 satellites in 3 orbits
  - at 56° inclination
  - with an orbital radius of 29’993.707 km, i.e. an orbital height of about 23620 km
  - Resulting in an orbital duration of 14 h 22 min
  - The constellation repeats after 10 days

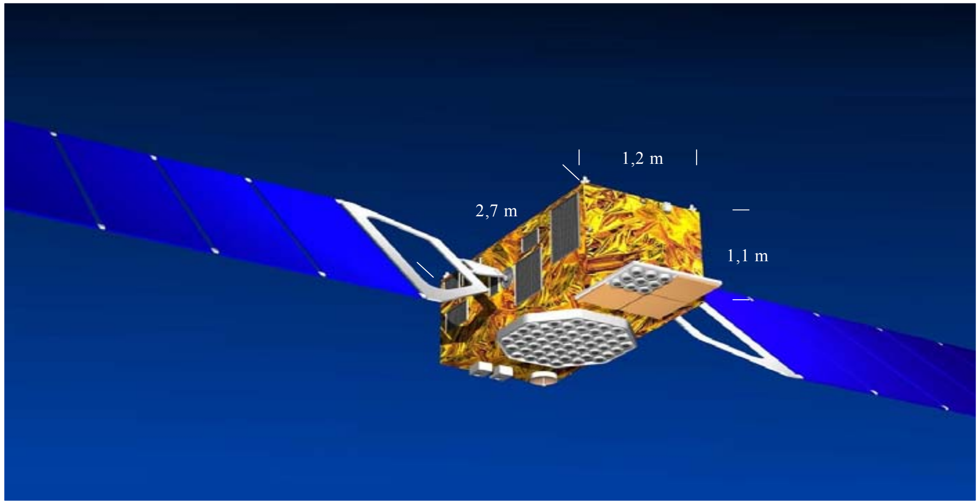
- Highly precise orbits allowing 3 years without correction



Galileo satellites

Galileo satellites

- 30 identical satellites
  - 27 active / 3 reserve
- Satellite features (tbd)
  - Weight 680 kg
  - Power 1.6 kW
  - Navigation Payload 115 kg
  - Life span 15 years



Source: ESA

- Steps
  - GSTB V2: 2 Test satellites (2005/6)
  - IOV: 4 Test satellites
  - FOC: 26 satellites till 2010

one by **Surrey Space Technology Limited** (SSTL), UK
the other one by **Galileo Industries**, a European consortium including Alcatel Space Industries (F), Alenia Spazio (I), Astrium GmbH (D), Astrium Ltd (UK) and Galileo Sistemas y Servicios (E)

- Launcher options:
  - Ariane (8 Satellites at a time)
  - Soyuz (2 Satellites at a time)

Galileo satellites

Galileo GSTB V2A satellite: Giove A

- Build by Surrey Space Technology Limited
  - Lift-off mass: 600kg
  - Power demand: 700 W
  - Stowed dimensions: 1.3 m x 1.8 m x 1.6 m
- Mission
  - Meet requirements for Galileo frequency filings
  - Transmission of Galileo signals
  - Test critical technologies like rubidium atomic clock

Successful launch on Dec 28, 2005

Source: ESA

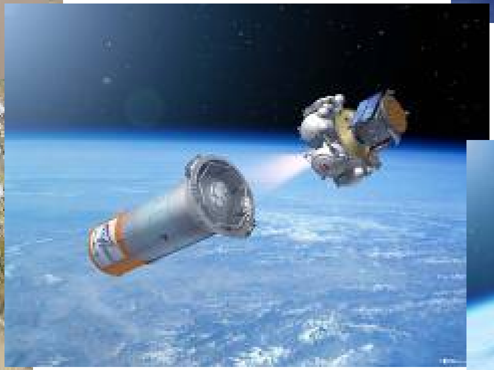
Galileo GSTB V2B satellite: Giove B

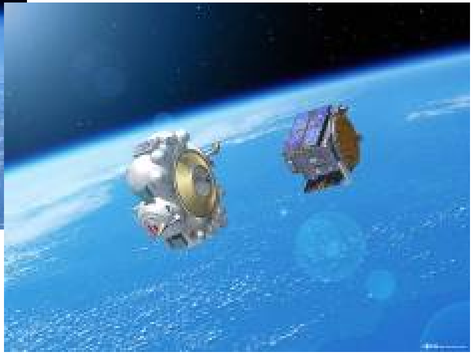
- Build by Galileo Industries
  - Lift-off mass: 523kg
  - Power demand: 943 W
  - Stowed dimensions: 1 m x 1 m x 2.4 m
- Mission
  - Transmission of Galileo signals
  - Test critical technologies like rubidium atomic clock, passive hydrogen maser clock

Source: ESA

Galileo satellites

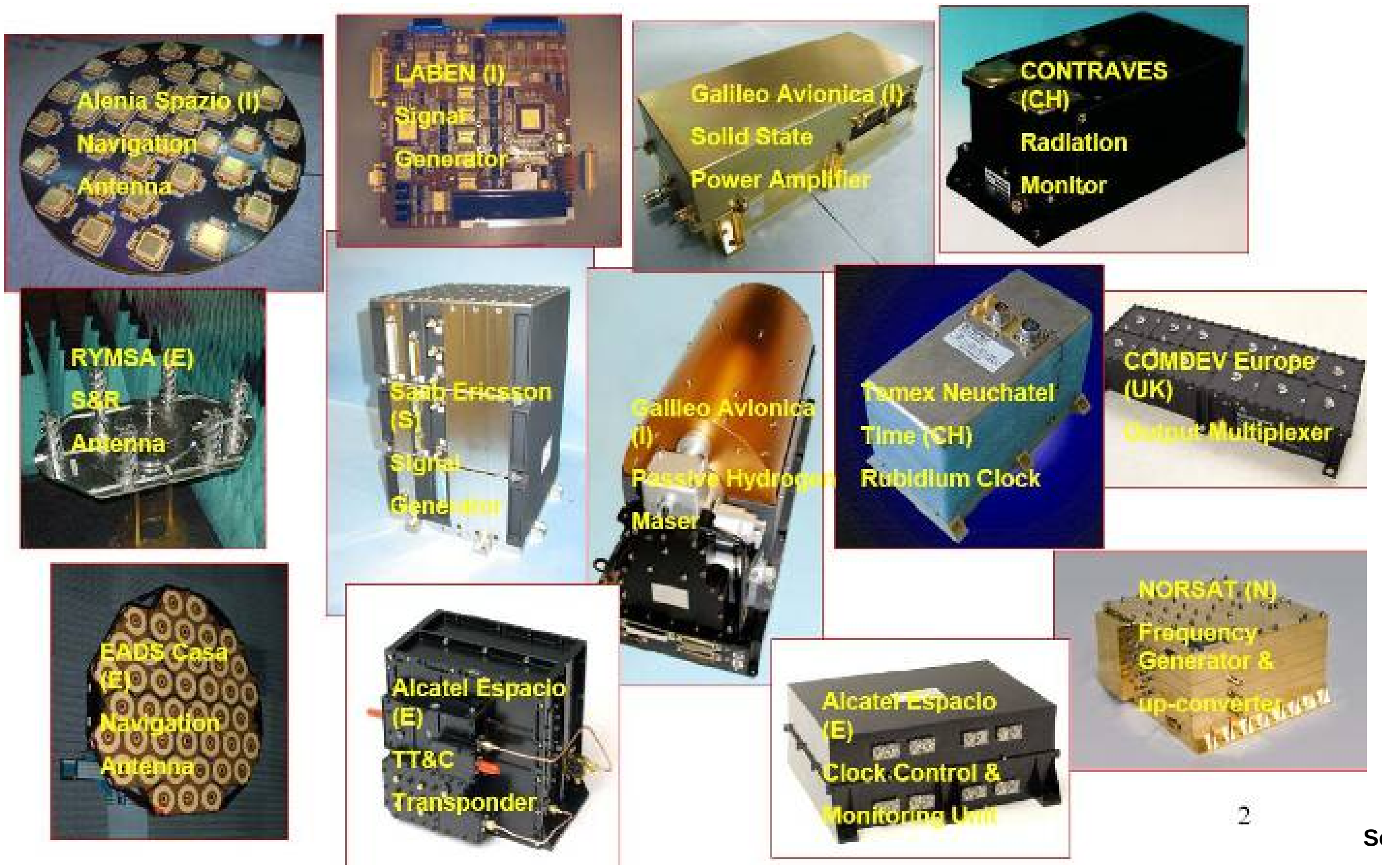
Giove A





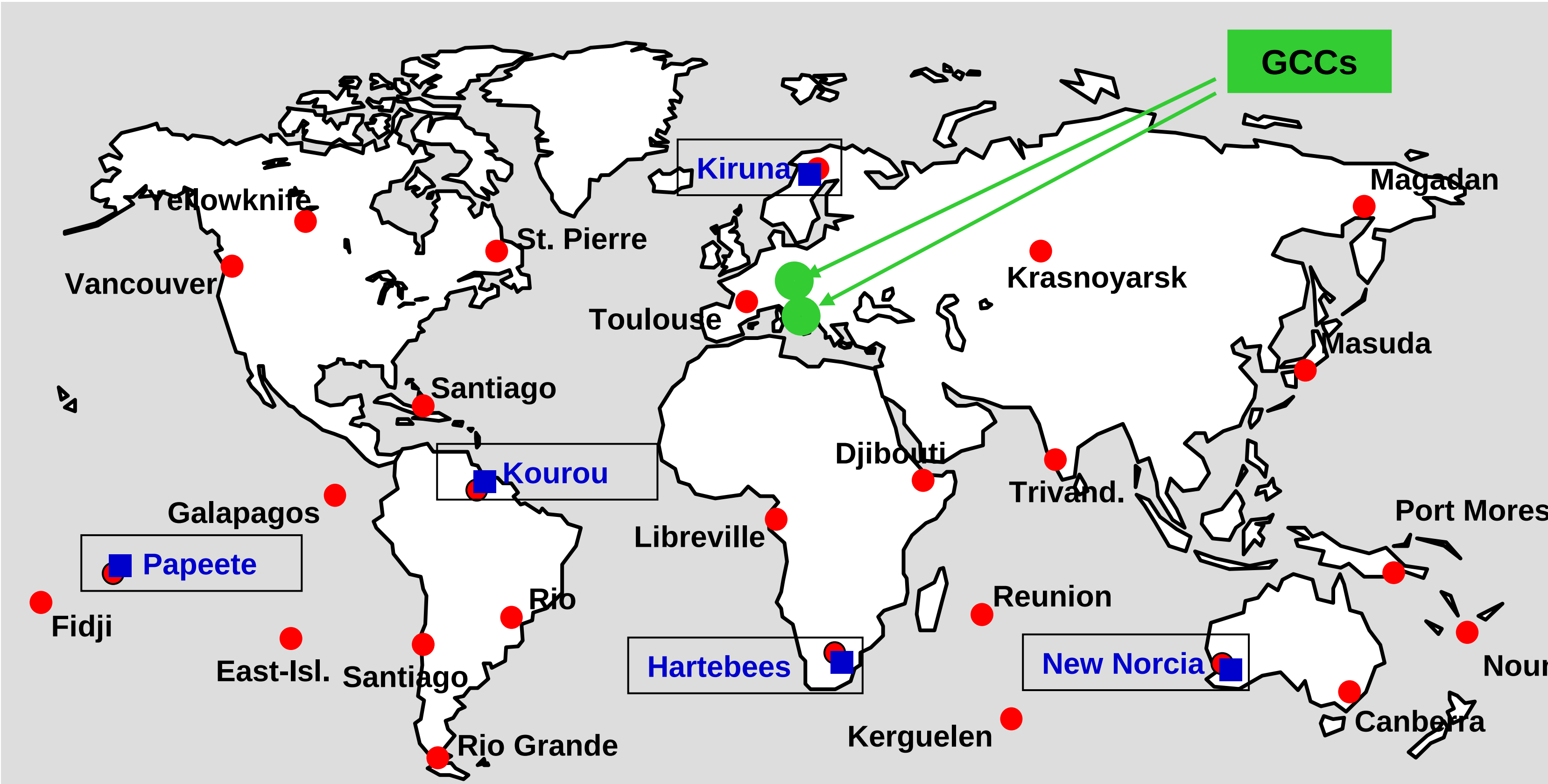
Galileo satellites

European key components for the experimental satellites



Source: ESA

Galileo monitoring network

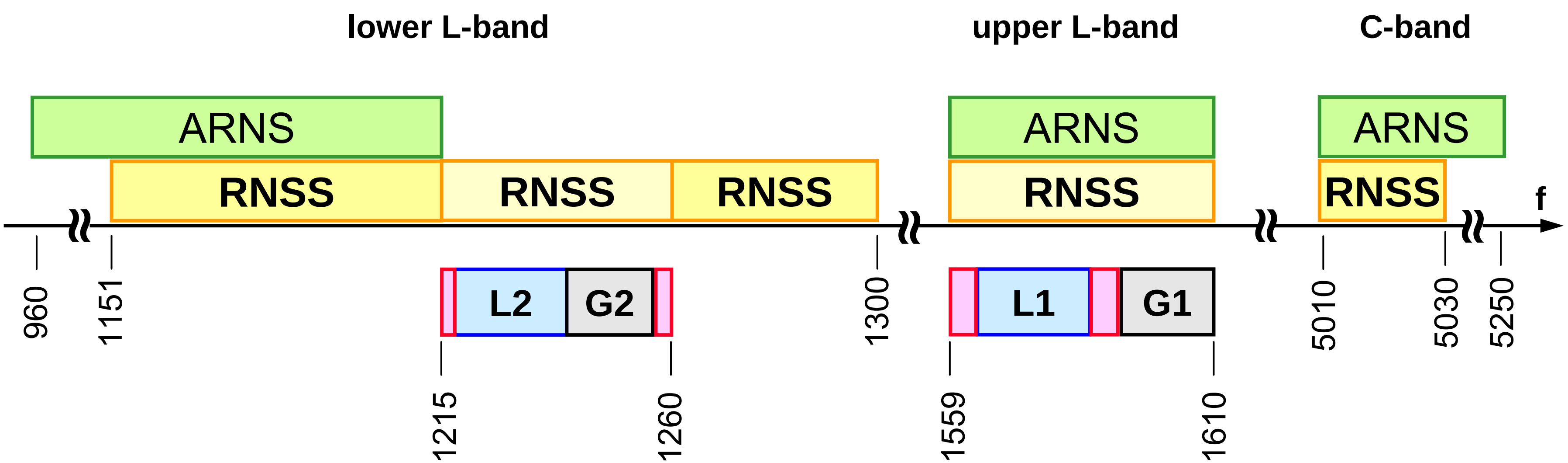


Note.: Utilization of the locations is matter of ongoing assessment

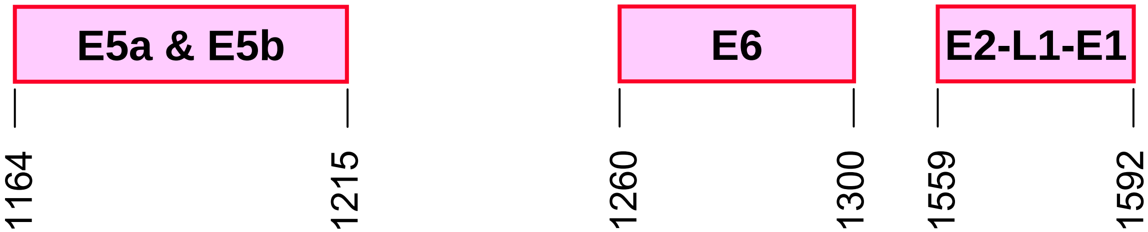
Dense monitoring network to enable accurate monitoring of satellite

Frequency assignments

WRC 2000: New frequency allocations for GNSS

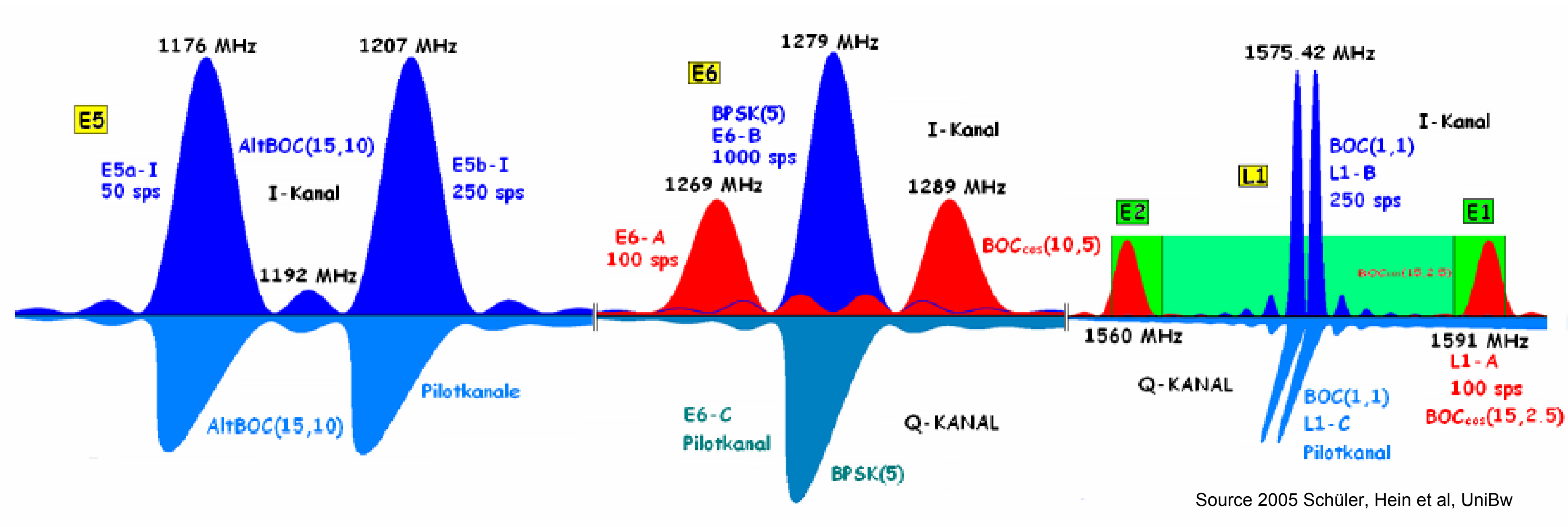


Allocations for Galileo

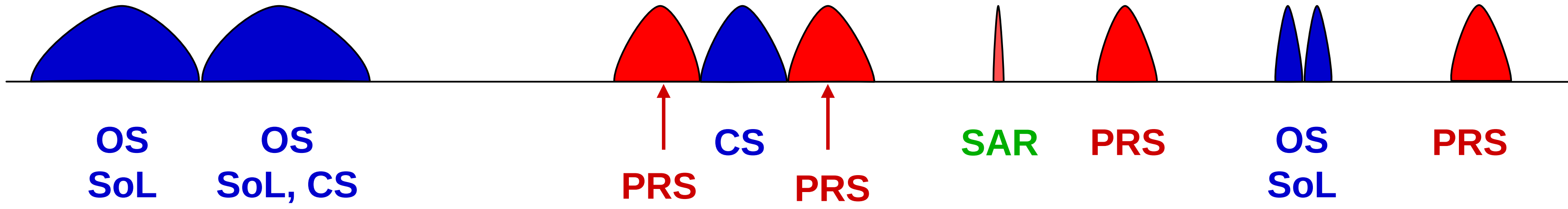


Galileo signals

Possible Galileo signals

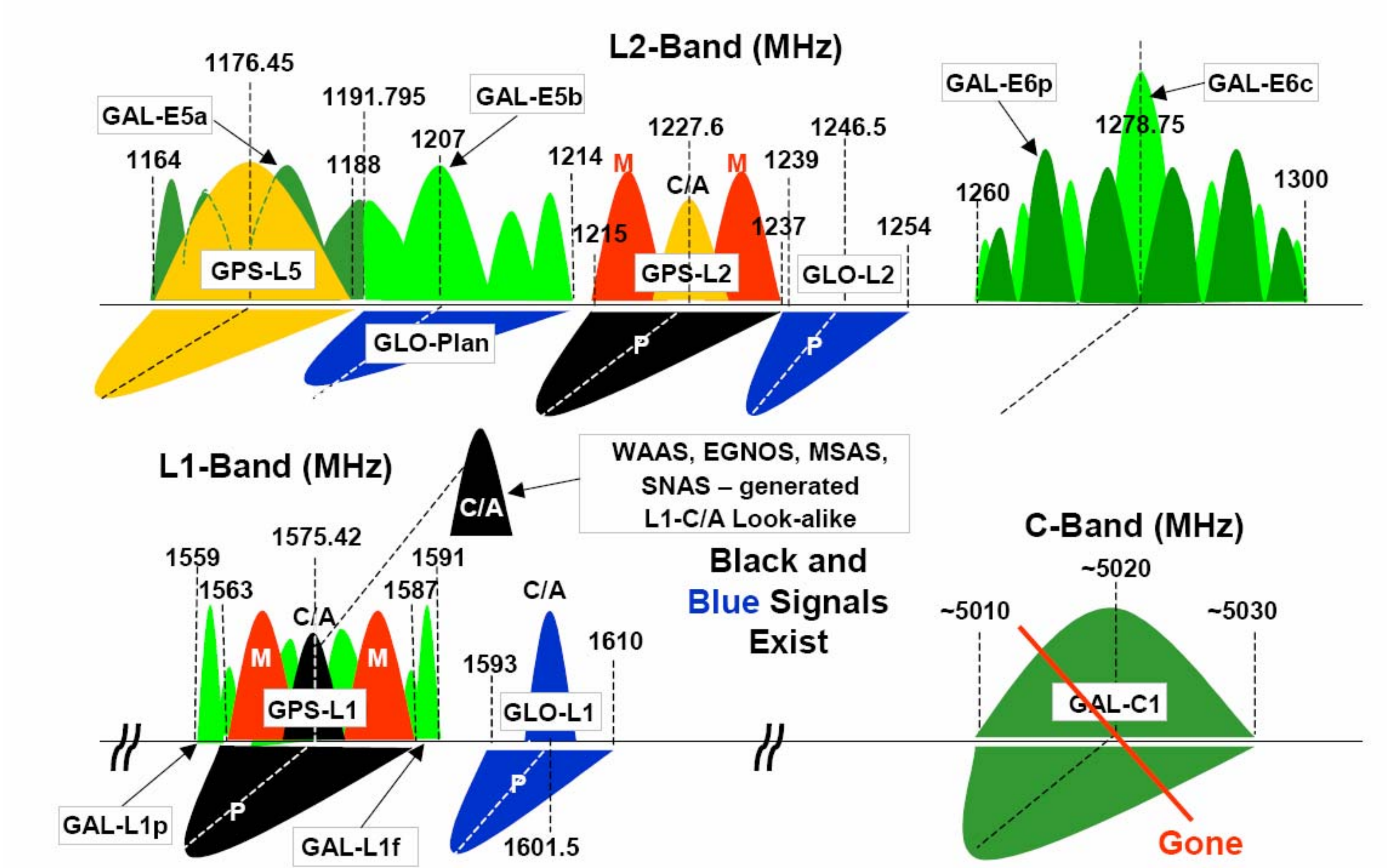


Source 2005 Schüler, Hein et al, UniBw



Today's and future GNSS signals

Part II



Source 2004 Fruehauf, FEI-Zyfer

Galileo service types

	Open service (OS)	Safety of Live (SoL)	Commercial service (CS)	Search & Rescue (SAR)	Military (PRS)
Technical features	Open signal, 2 frequency bands, common frequency (L1) with GPS	Same frequency bands as OS, additional integrity information	3 frequency bands, two of them overlapping; to be defined by concessionaire	Emergency call with return channel; possibly SMS-service	2 separate frequency bands
Advantage of Galileo over GPS	Higher availability, better DOP, better accuracy	Integrity	High accuracy, integrity	Ambiguity resolution	Independ ence
Examples	Logistics, car navigation, road toll, personal navigation	Air traffic, sea & harbour, rail, road	Geodesy, construction, agriculture	Emergency calls	Blue force, weapons

Safety of live (SoL) and commercial services

SoL applications are of high importance

- Air: En route guidance and aircraft landing
- Rail: Increasing traffic
- Sea: Enabling precise harbour approach
- Road: Driver assistance

Commercial services with large economic impact

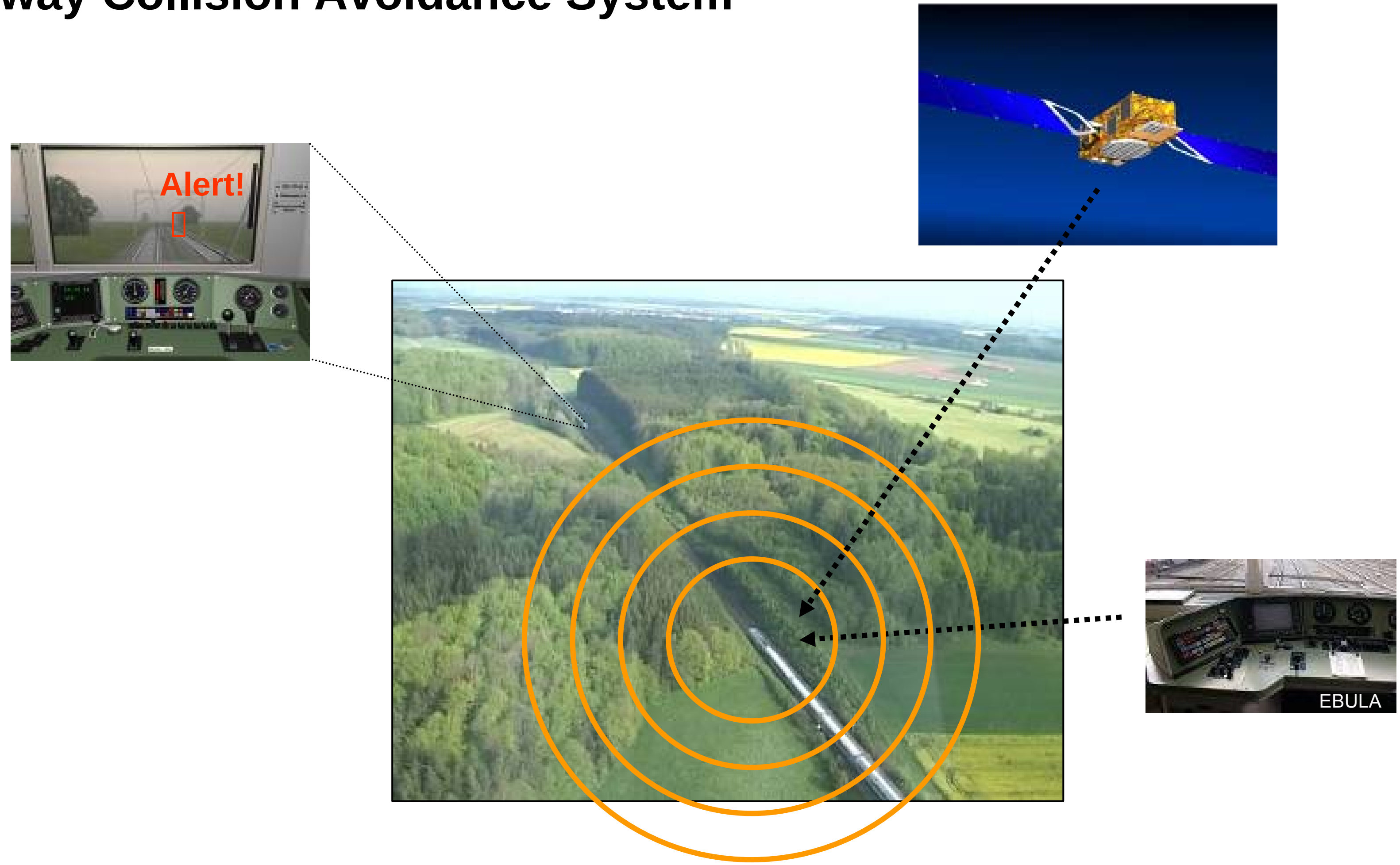
- Synchronisation of power generation phases
- Synchronisation of monetary transactions
- Synchronisation in mobile radio networks
- Road tolling, construction work

Source: EU

Galileo offers several civil signals, QoS, service guarantees, contractual operator, integrity information

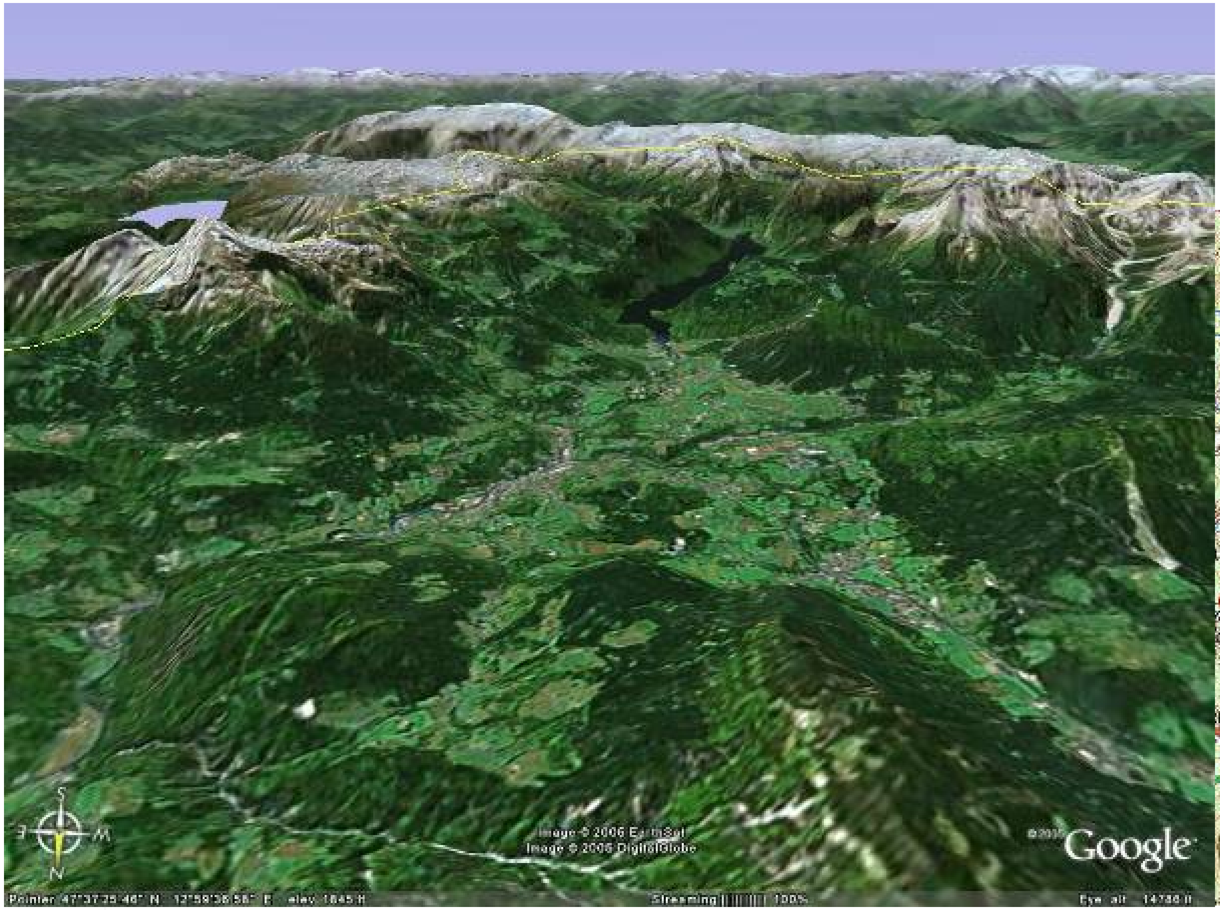
Safety of live (SoL) services

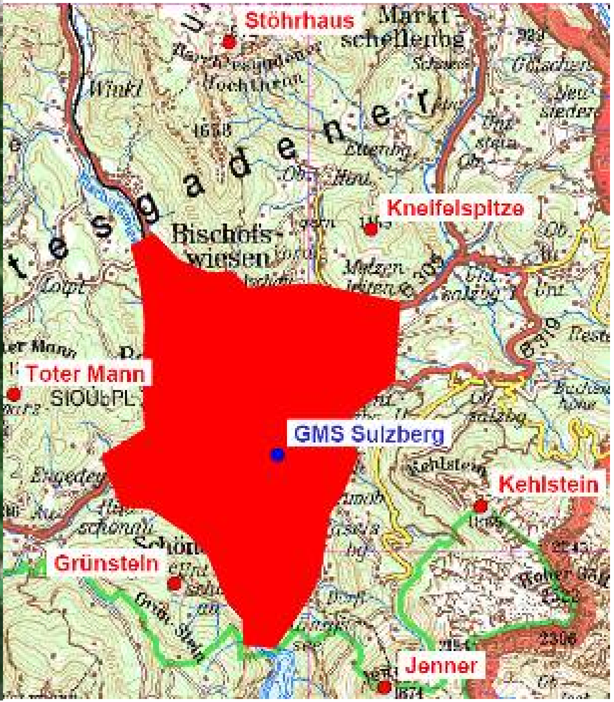
Railway Collision Avoidance System



German Galileo Test Environment GATE

Gate: The German Galileo Test Environment



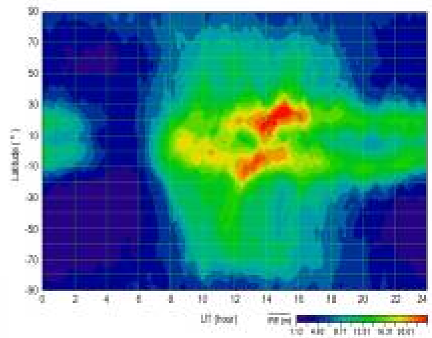


DLR R&D involvement in Galileo

Applications

Ionosphere

Local elements



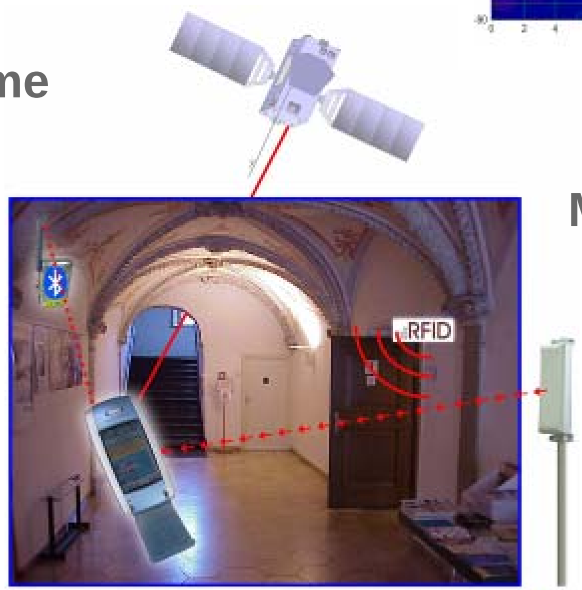
Simulation: NavSim

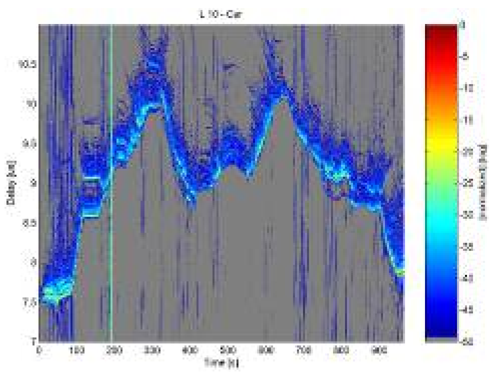
Receiver techniques

Verification

Multipath

System time





Monitoring

Indoor

EVNet

Context-aware services

Thank you for your attention