The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

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# Galileo Systems and Services

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# GALILEO System and Services

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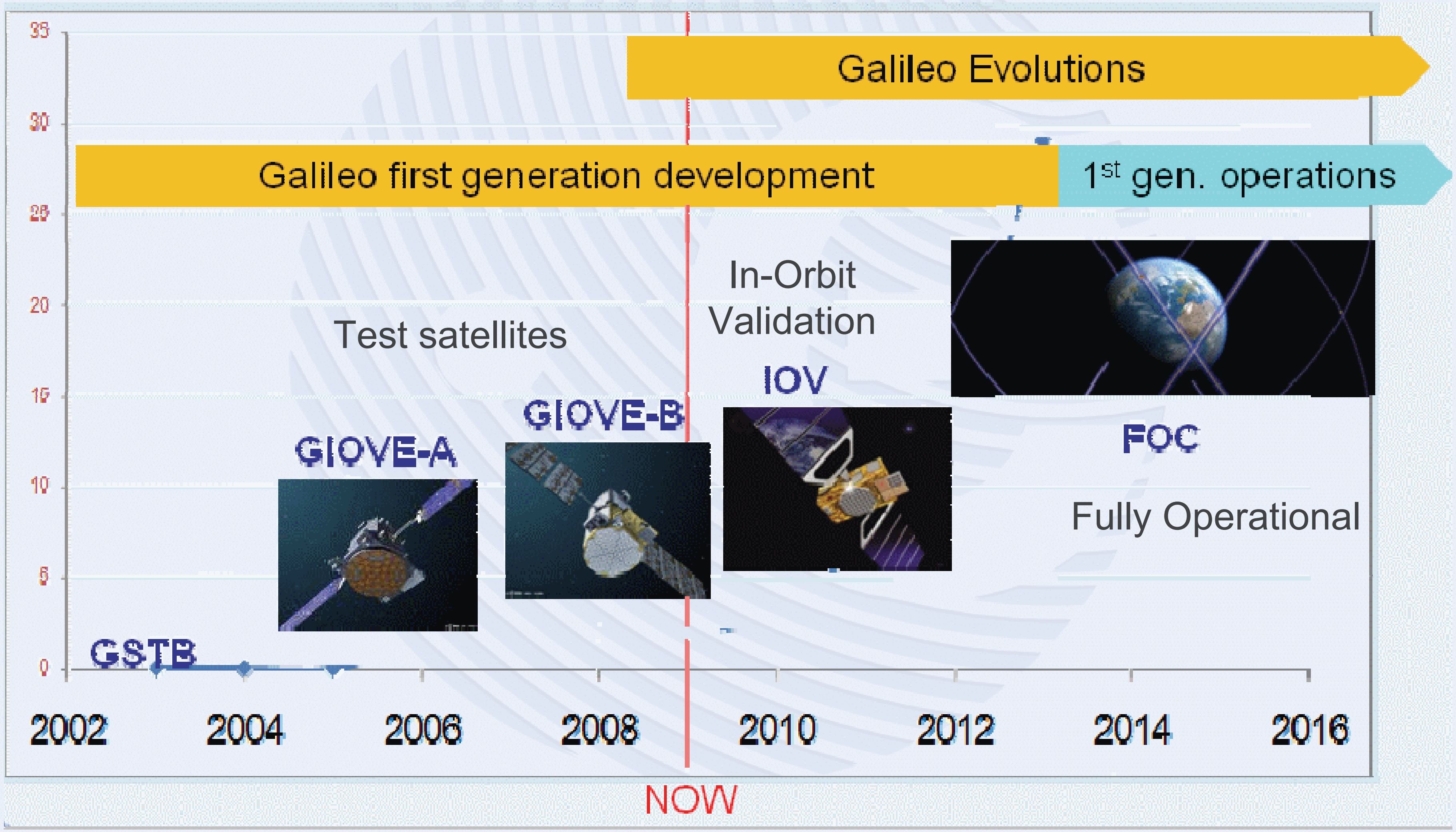
# The GALILEO Programme

# Galileo History

- Mid 1980s   First studies for European Sat Nav programme commissioned by ESA, CNES and DLR.
- 1994 European Commission launches proposal to engage in satellite navigation.  EuroControl, ESA and EC form partnership to develop EGNOS  (European Geostationary Overlay System) in response to INMARSAT ITT.
- 1997 Work on the definition of a global navigation system (then called GNSS-2) starts.
- 1999 The new European SatNav System is named "GALILEO" – the programme is to executed jointly by ESA and the European Commission.
- 2002 EC Transport council approves Galileo
- 2003 ESA Council approves funding of the GalileoSat Programme

# Timeline of Galileo Program

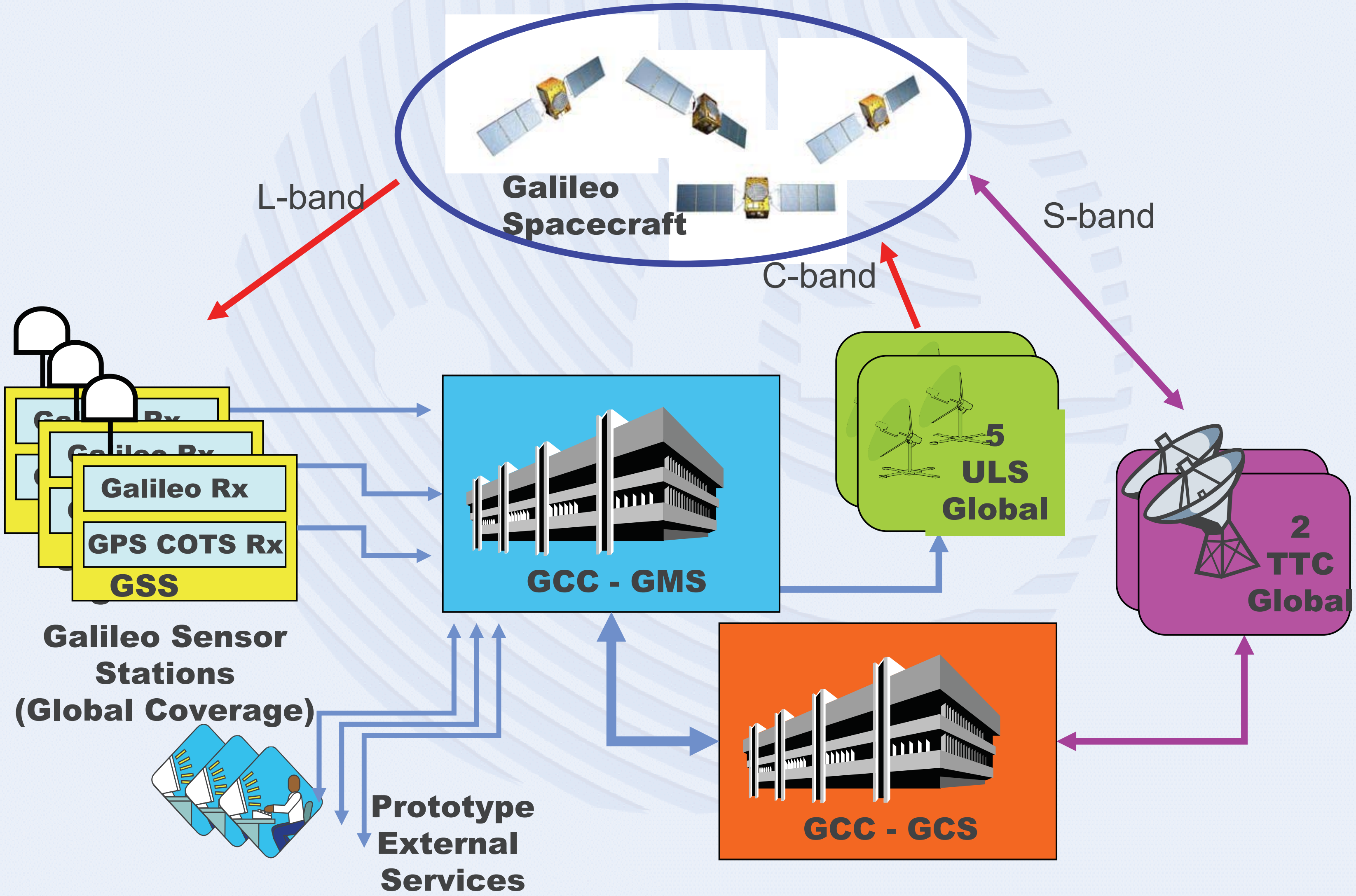


# The GALILEO System

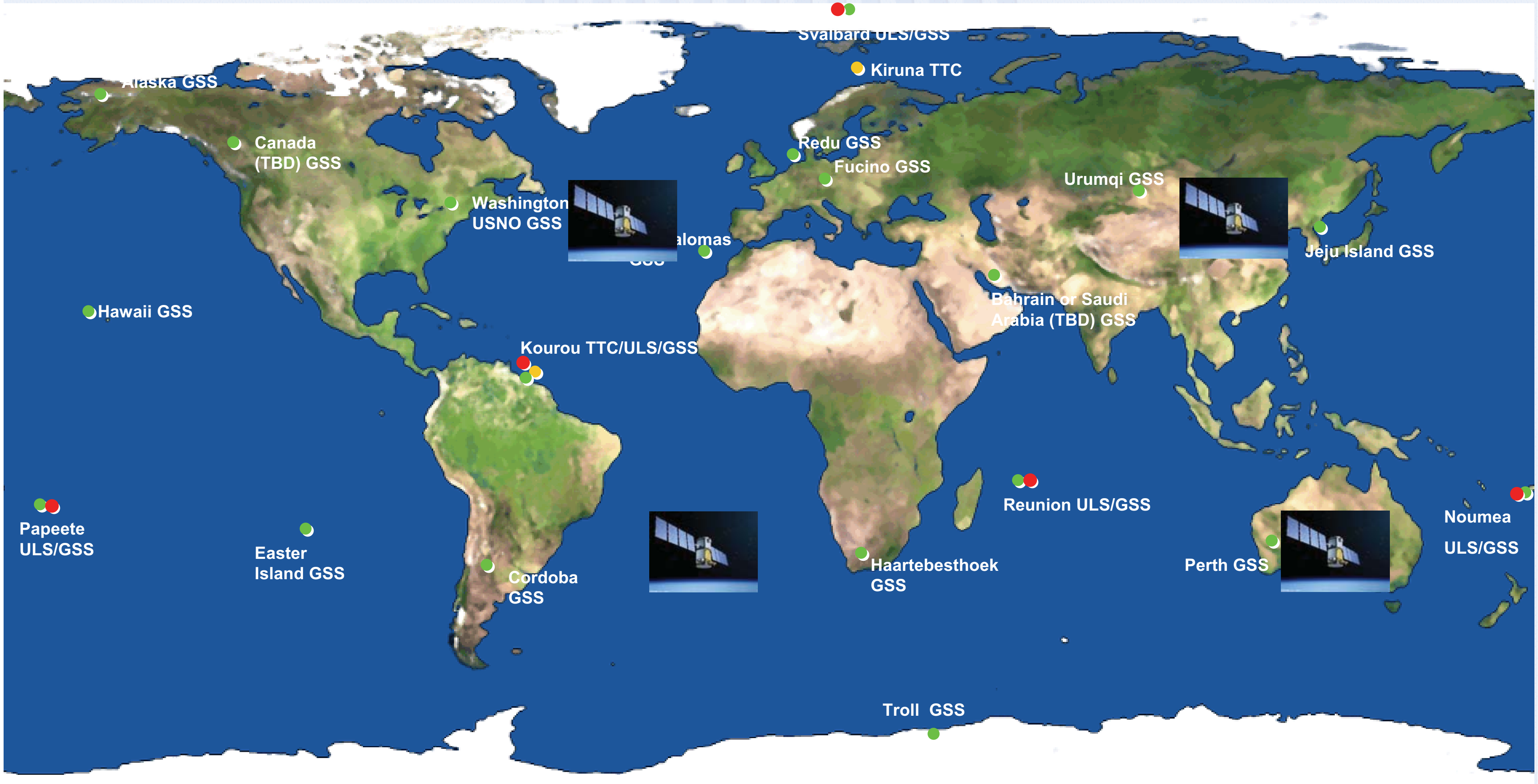
# Galileo Characteristics

- Independence of other satellite navigation systems
- Interoperability with GPS and GLONASS
- Designed for allowing different services
- Provides integrity for safety-critical services (with or without augmentation)
- Intended primarily for civilian applications
- Built-in Regional and Local components
- Guaranteed service
- Fully interoperable with other GNSS components

# Galileo System Architecture



# Galileo IOV Infrastructure




- 18 GSS
- 5 ULS
- 2 TT&C
- 2 GCC
- 2 LOCC
- 1 IOT

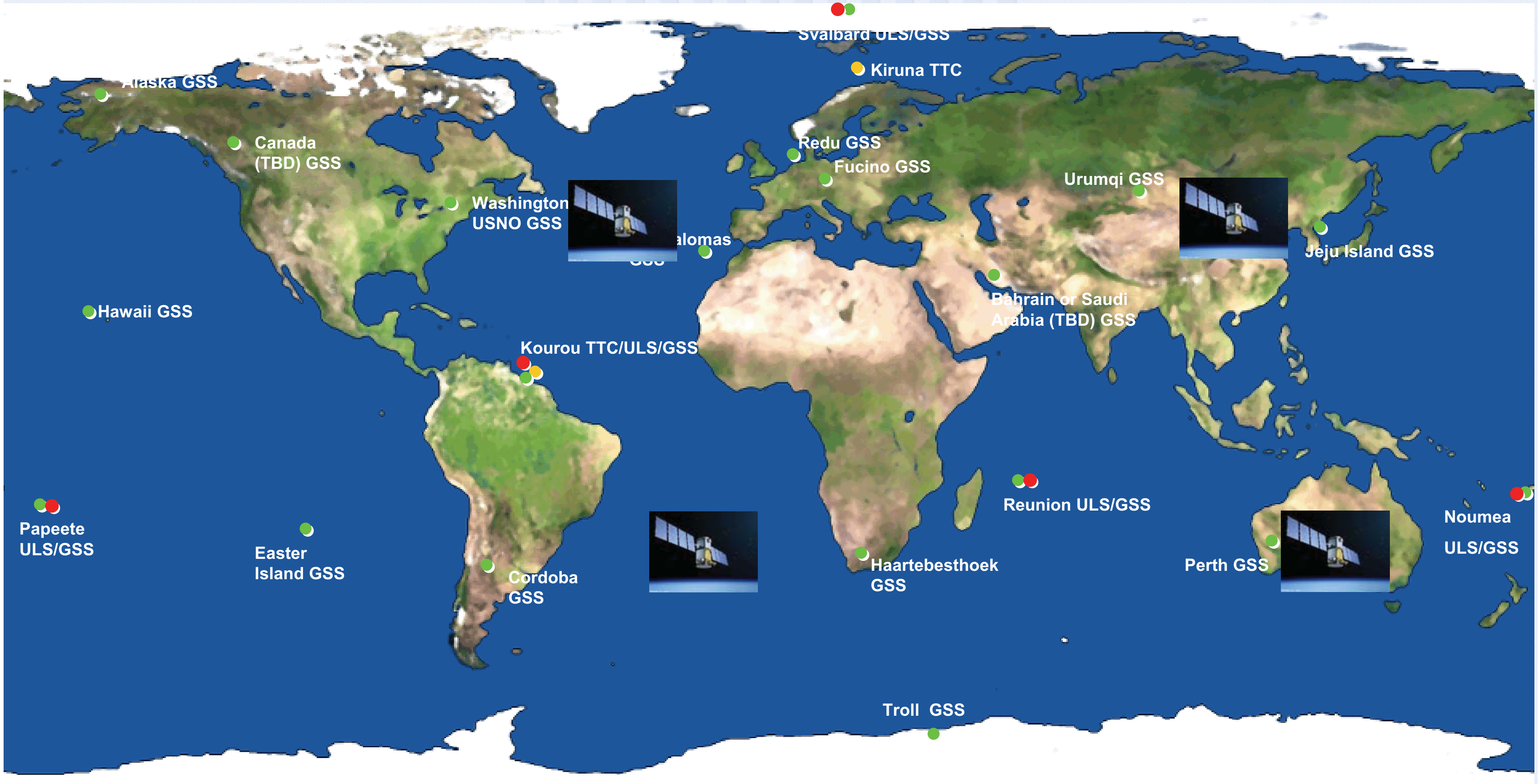
# Galileo Architecture Aspects

- **SCALABLE Architecture**: evolution from one mission phase to the next is done by deployment/removal of elements and not by re-design of concepts/parts of the system
- **ADAPTABLE Architecture**: system architecture can adapt to evolution of technology and service requirements.
- **STEPWISE DEPLOYABLE Architecture:** The Galileo system is deployed in phases to meet the programmatic constraints of the Galileo program (Cost, Verification, Schedule, etc.)

# Galileo Design Aspects

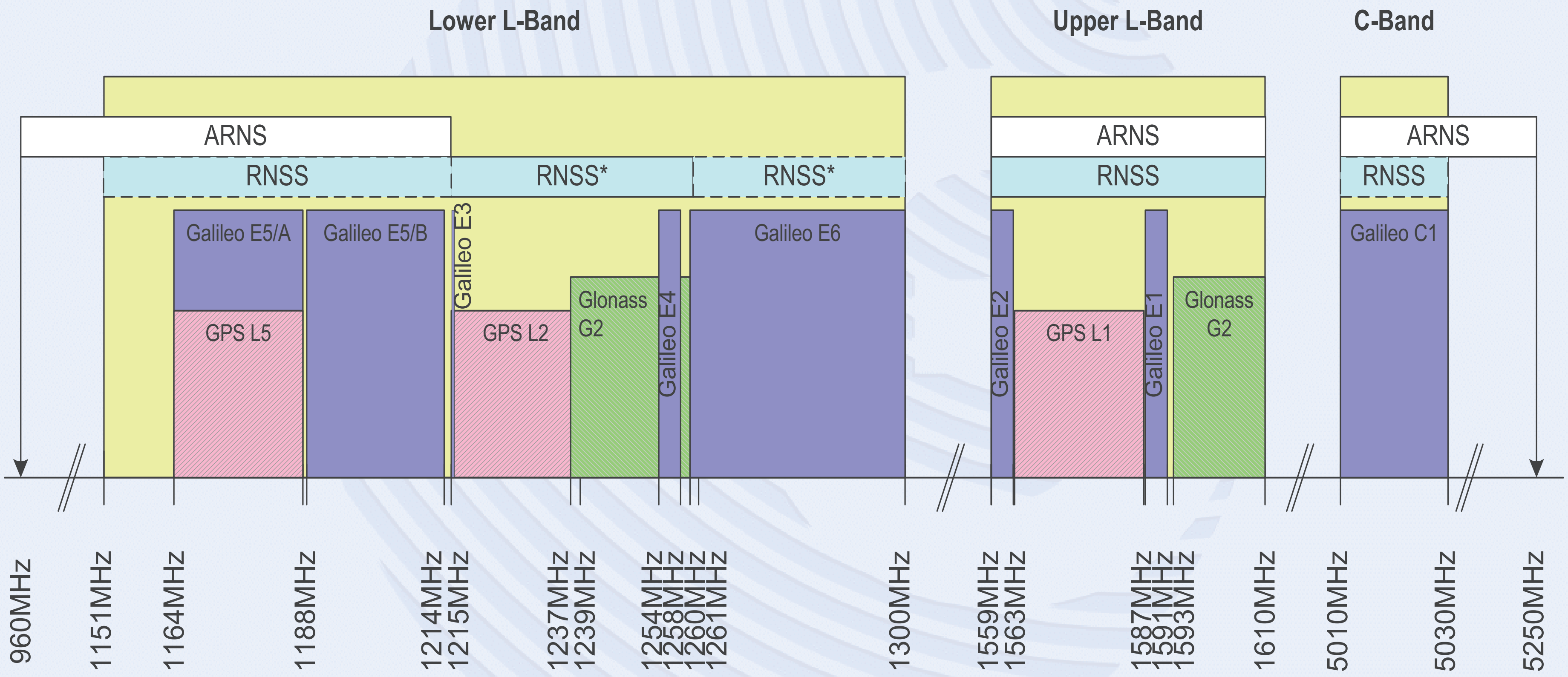
- Mission data (Navigation / Integrity / Search & Rescue) are up-linked separately from TTC data
- TTC up-link provided through 11-m S-band antennas
- Mission data up-link provided through C-band antennas
- Independent Search&Rescue Payload (incl. forward antenna) on board the satellite

# Galileo IOV Infrastructure




| | | | |
|---|---|---|---|
| ● | 18 GSS | ■ | 2 GCC |
| ● | 5 ULS | ● | 2 LOCC |
| ● | 2 TT&C | ● | 1 IOT |

# RNS Frequency Plan

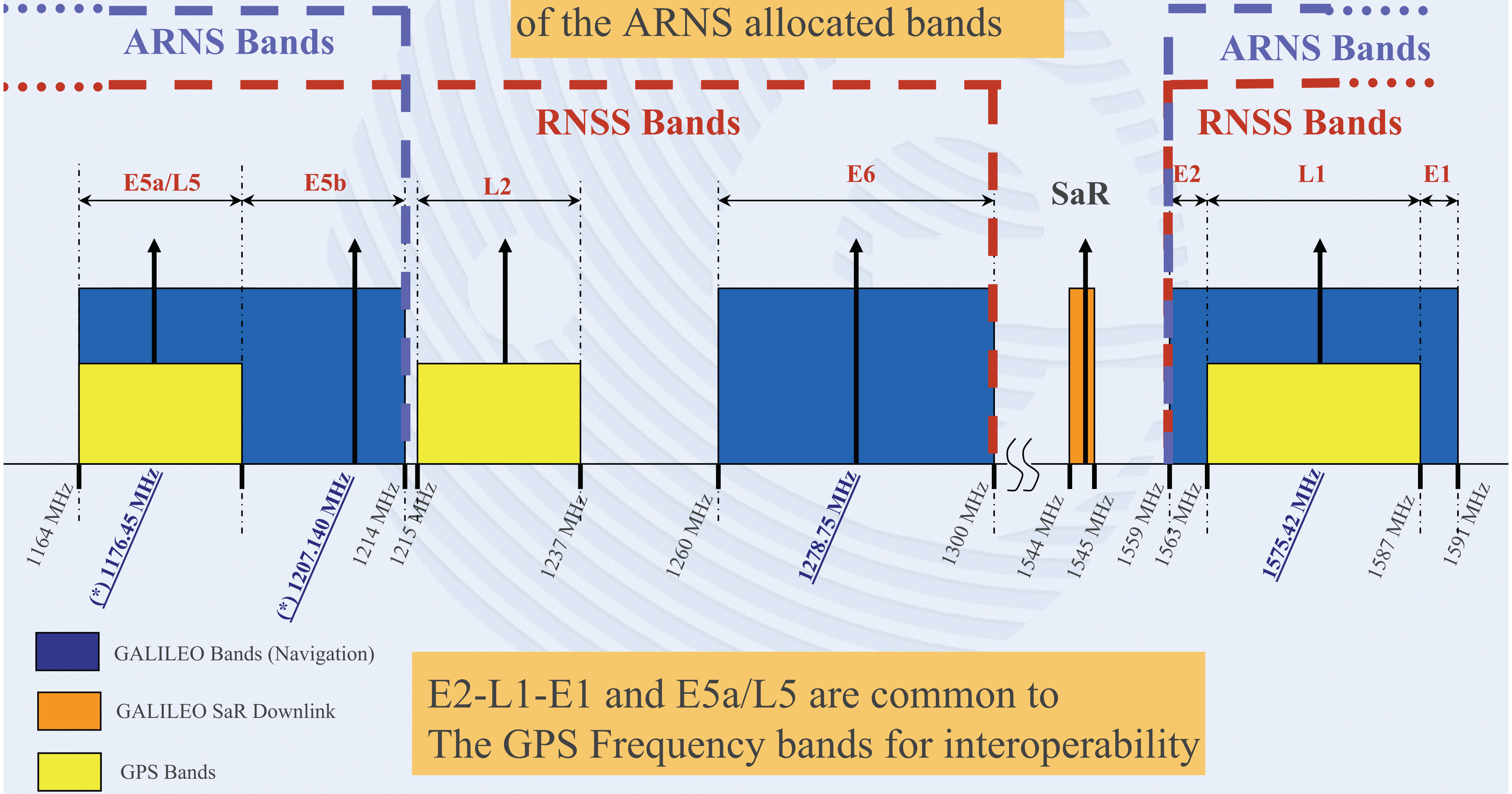



RNSS* shared with other services

RNSS Radio Navigation Satellite Systems
ARNS Aeronautical Radio Navigation Systems

# GALILEO Frequency Plan

Three Frequency Bands are part of the ARNS allocated bands

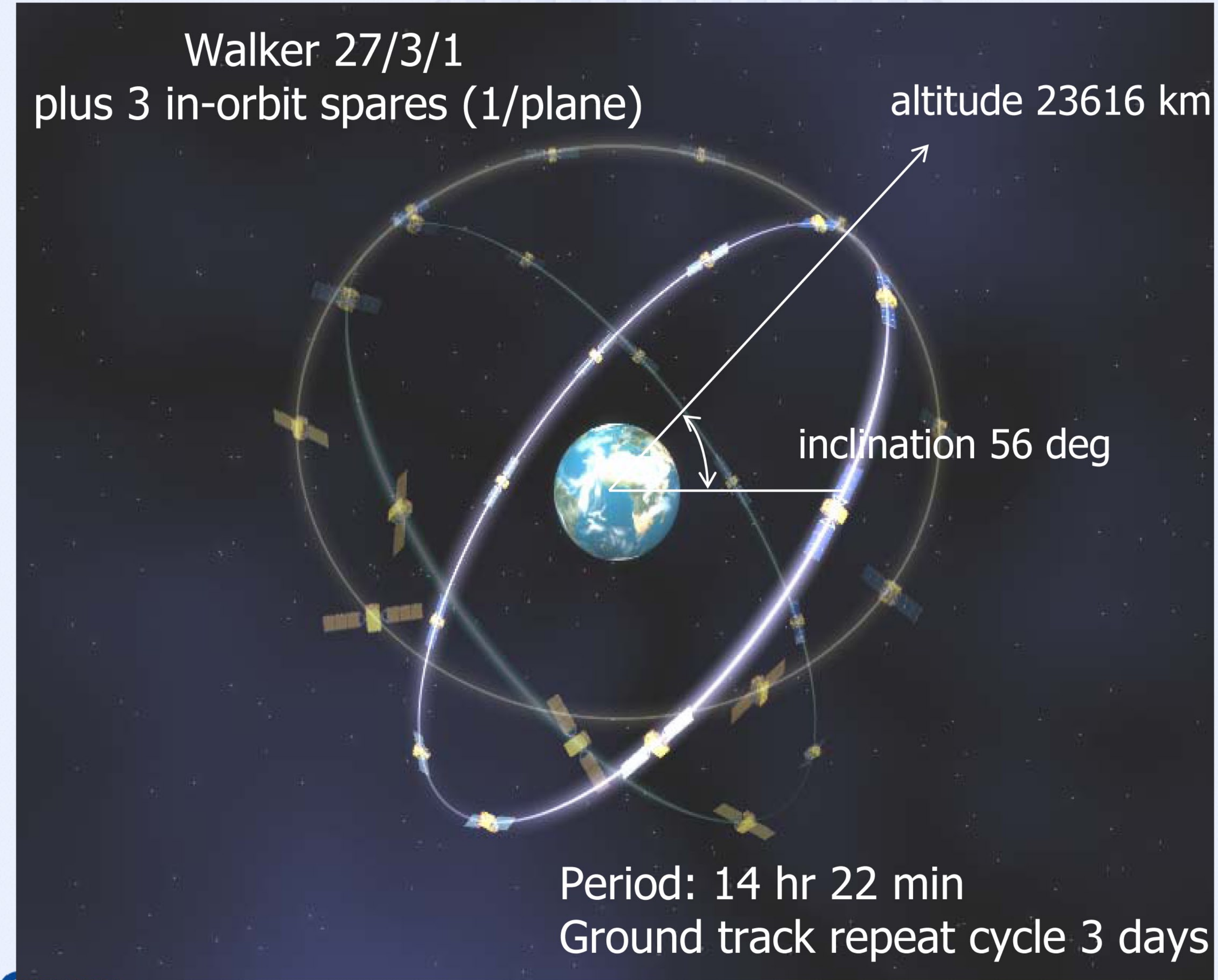


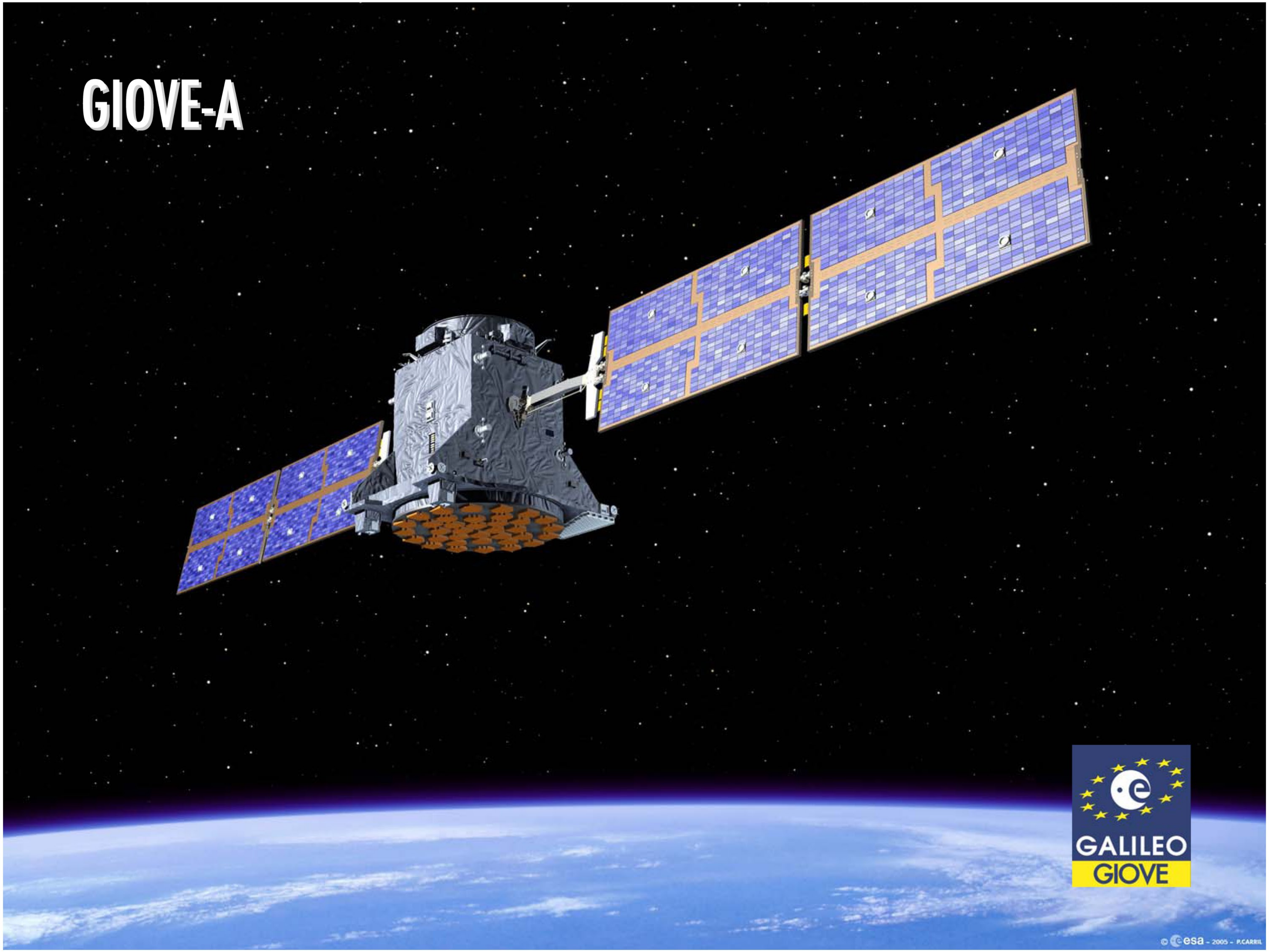

E2-L1-E1 and E5a/L5 are common to
The GPS Frequency bands for interoperability

# Space Segment Characteristics

- Constellation of 30 spacecraft including in-orbit spares
- MEO orbit of 23616 km, with direct orbit injection as baseline
- Spacecraft transmit continuous ranging codes & navigation data
- Integrity data are up-linked every second and the data are passed via a separate on-board data path to guarantee short Time to Alarm (TTA)
- Spacecraft have autonomous capability in the event of loss of ground contact or failures
- Spacecraft lifetime 12 years, system lifetime 20 years

# Galileo Constellation




GIOVE-A
GALILEO
GIOVE
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GIOVE-B
GALILEO
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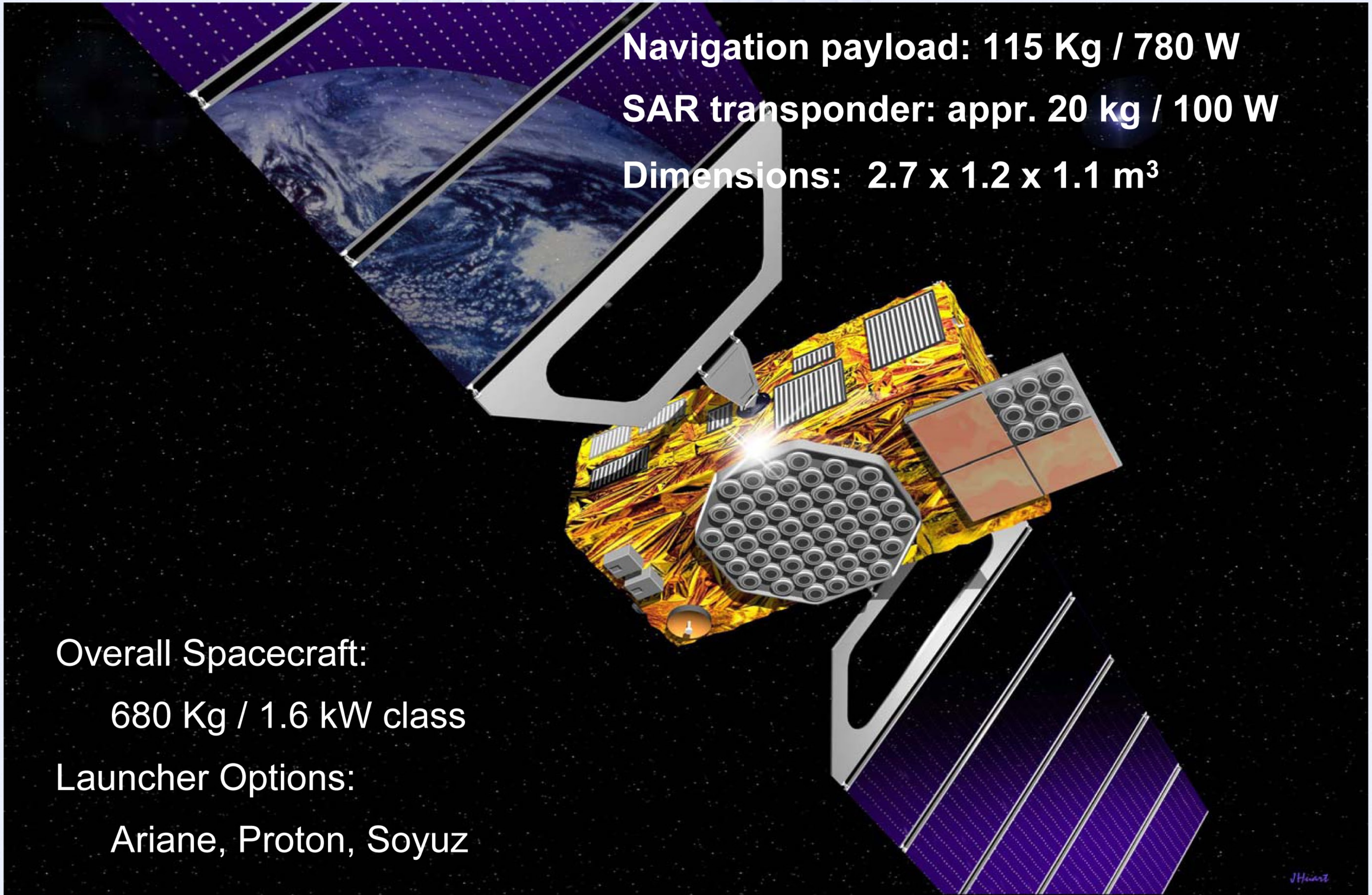
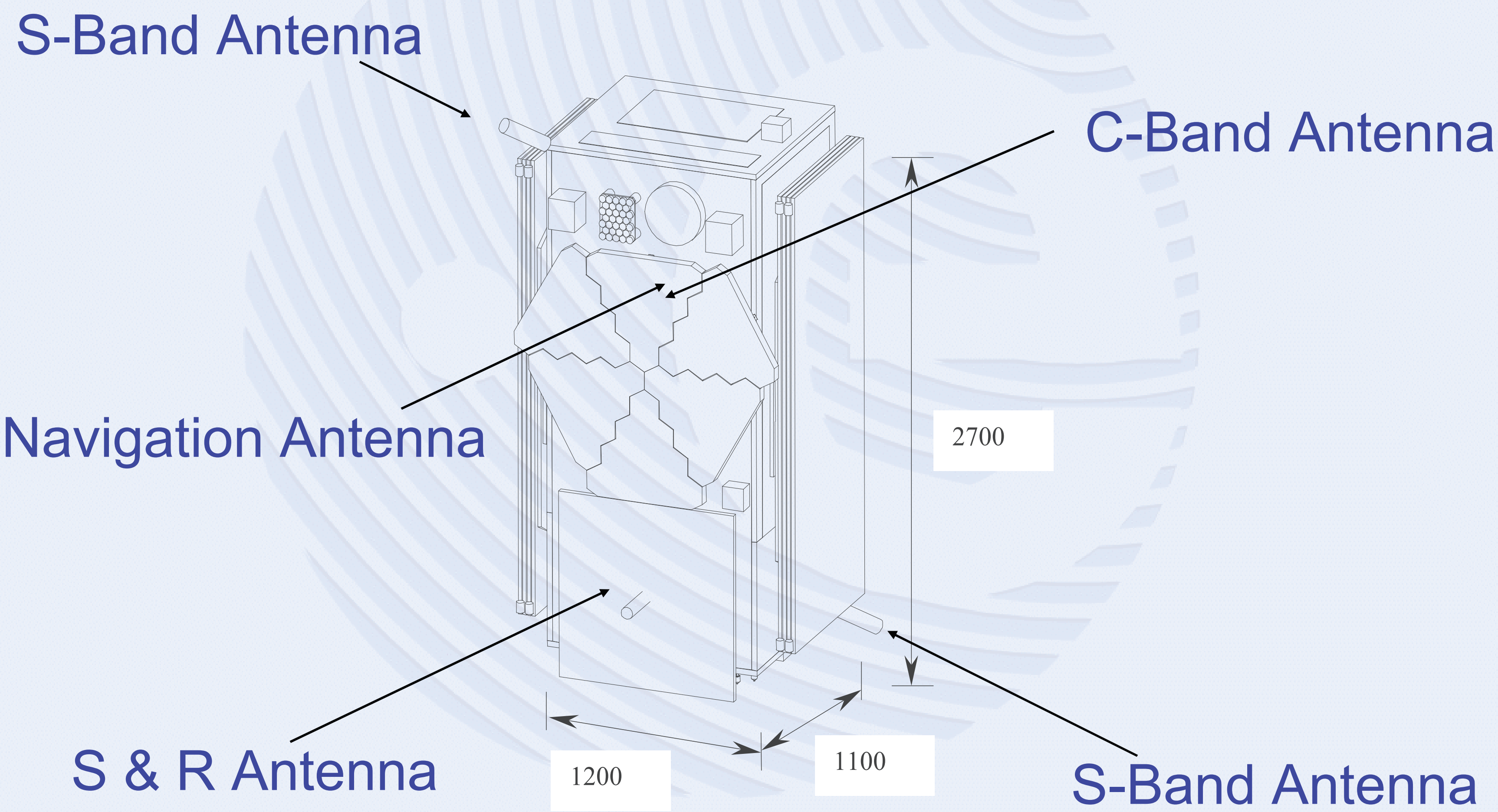
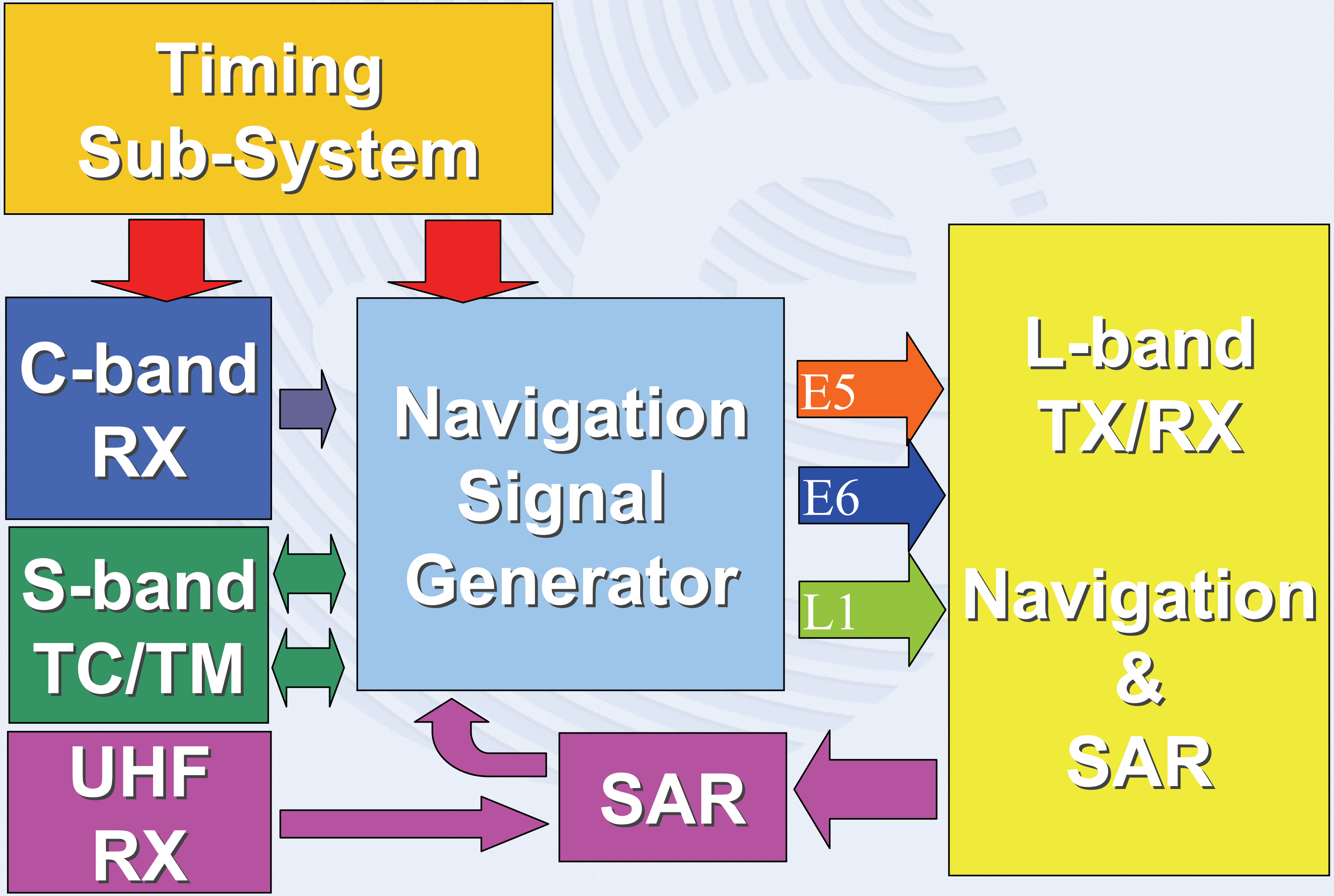
# Galileo Spacecraft (1)



# Galileo Spacecraft (2)



# Galileo Payload (1)



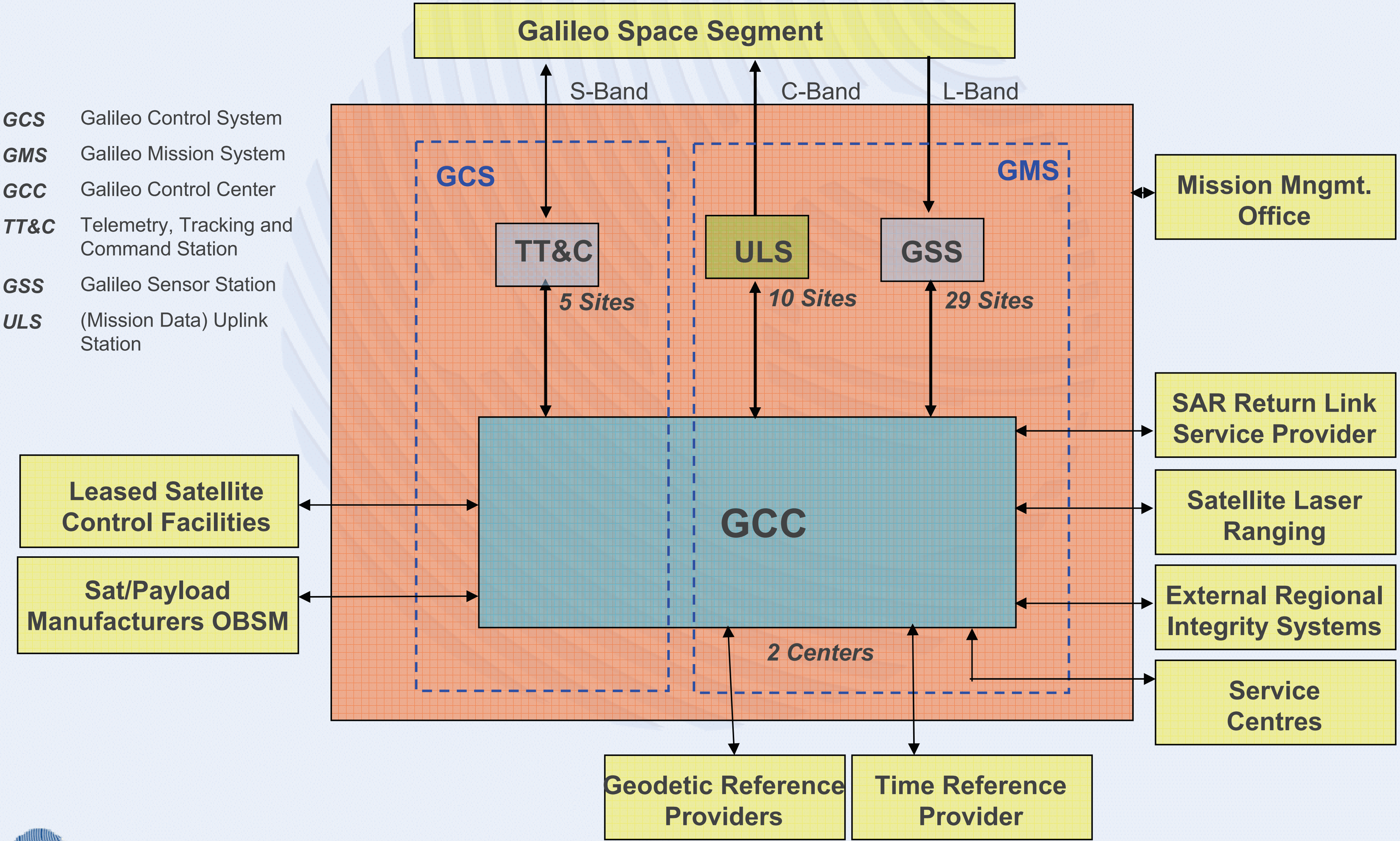
# Galileo Payload (2)

- The timing subsystem has two pairs of redundant clocks, each pair comprising two different technologies (Rubidium Clock and Passive H-Maser)
- The signal generation subsystem provides formatting, encoding & modulation of carrier frequencies, controlled by the navigation processor
- The RF subsystem amplifies the modulated carriers, the baseline being use of solid state power amplifier technology
- The antenna subsystem transmits the navigation signals to users
- The C-band Rx subsystem receives navigation and integrity (mission) data uplinks from ground (up to 6 channels simultaneous)

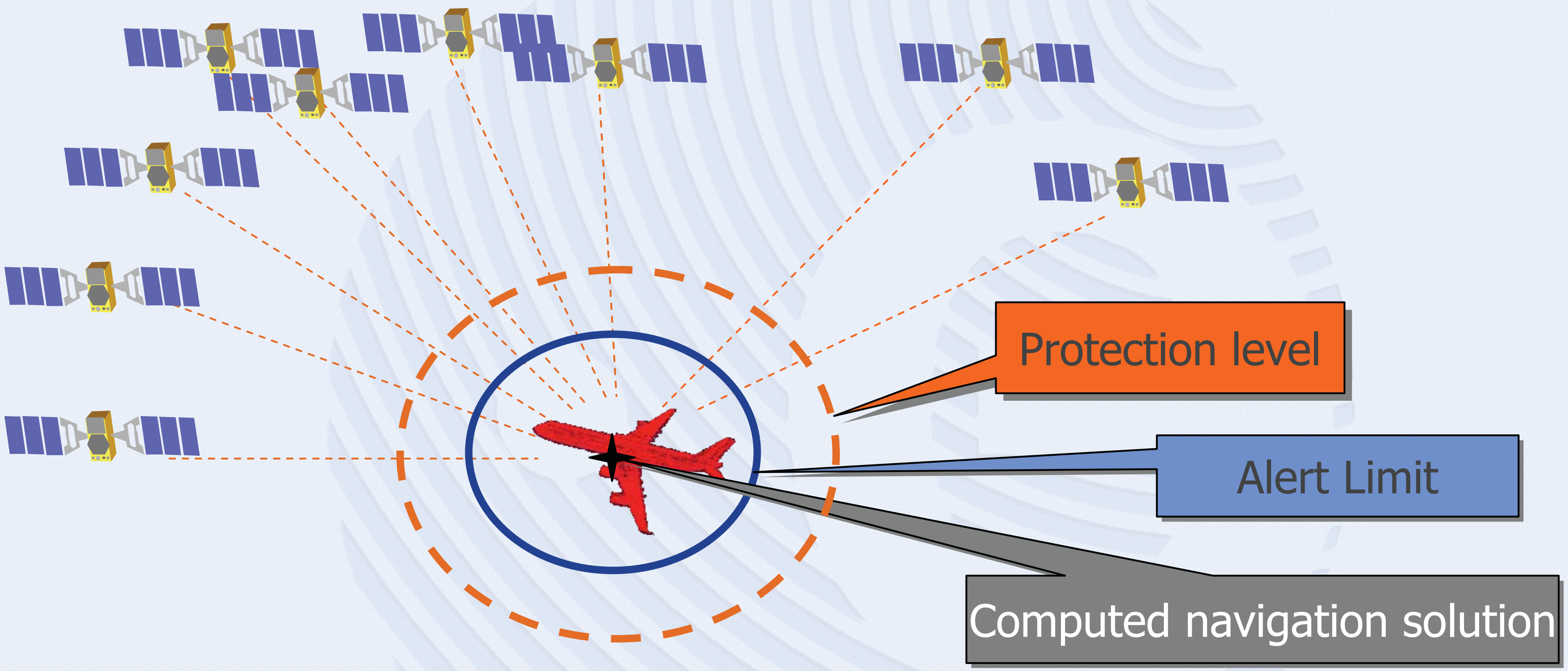
# Galileo Clocks

- Rubidium Atomic Frequency Standard (RAFS)
  - Very good short term stability
  - 3.3 kg mass
  - 30 W power
- Passive Hydrogen Maser (PHM)
  - Excellent long term stability
  - frequency-drift
  - 18 kg mass
  - 70 W power

# Ground Segment Architecture



# Galileo Integrity Concept

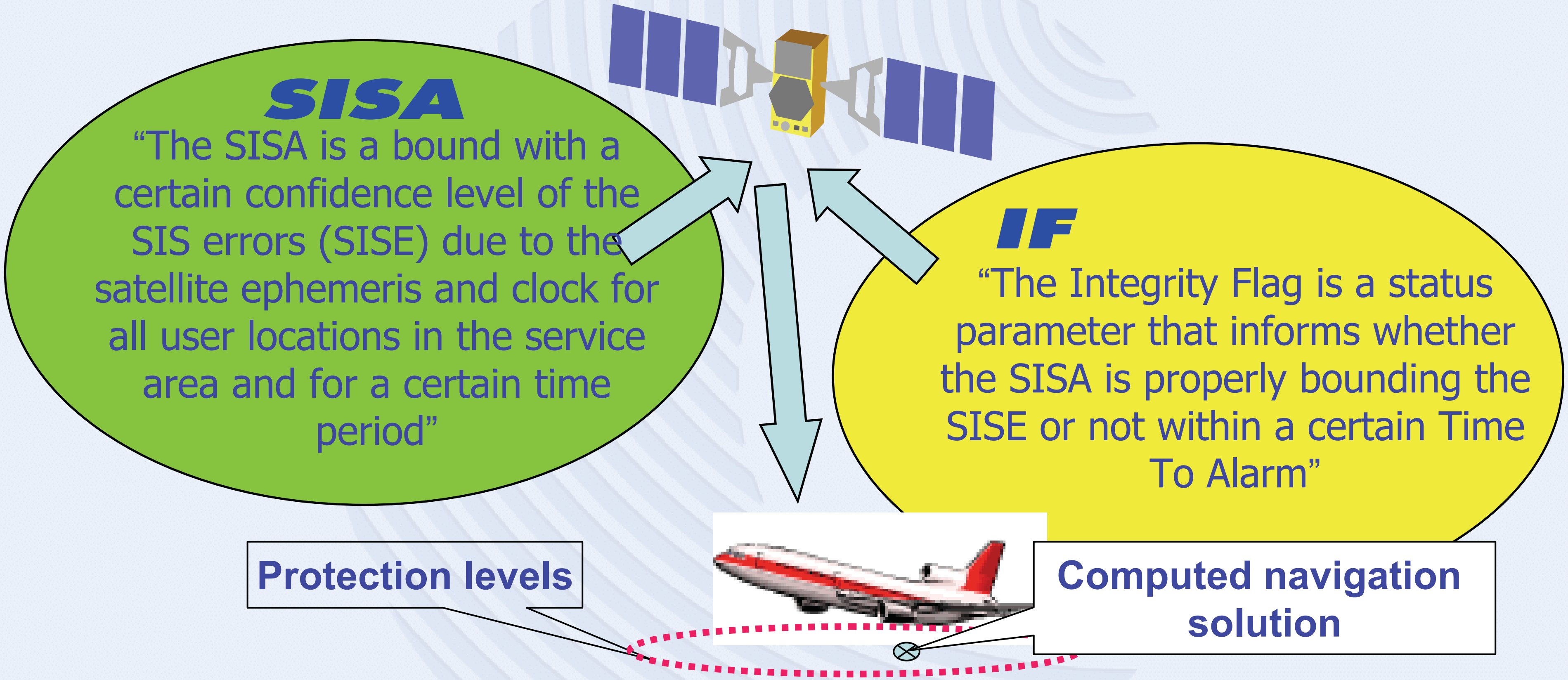



Alert Limit < Protection Level → **Alert (Abort Landing)**

Alert Limit > Protection Level → No Alert (Continue Landing)

The integrity function provides timely warning to the user that the accuracy of the service is not sufficient for the intended application

# Galileo - SISA and Integrity Flag




SISA (Signal in Space Accuracy) should correctly bound all errors

- Independent check performed by the Integrity Processing Facility
- Generation of **Integrity Flags** in case a feared event is detected
- Broadcast to the user of SISA + IF in the navigation signal

# Regional Integrity

- In addition to Global Integrity, Galileo architecture provides interfaces for Regional Integrity Networks

- Objectives:
  - Provide external Regions independent means to determine Galileo integrity for Safety-of-Life services (liability / certification)

- Functionalities:
  - Integrity determination through Regional IPF
  - Integrity dissemination through Regional ULS

# Galileo TTCF Antennas

TTCF Kiruna Antenna
Installed on site (Aug'08)

TTCF Kourou Antenna at Factory
Acceptance in Luxembourg (Jul'08)

# DLR Control Centre (GCC)

Located in Oberpfaffenhofen (Germany)

# Telespazio Control Centre (GCC)

Located in Fucino
(Italy)

Operational Building

Administrative Building

# Precise Timing Facility (PTF)


Maser clocks

# Integrity Processing Facility (IPF)


Also containing Orbit Synchronisation Processing Facility (OSPF)

# Galileo Single Freq. Iono algorithm

*SENSOR STATION*

**Observe slant TEC in Galileo Sensor Stations for 24 hours**

**Optimise effective ionisation parameter for NeQuick to match observations**

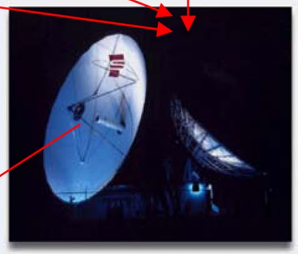
*SATELLITE*

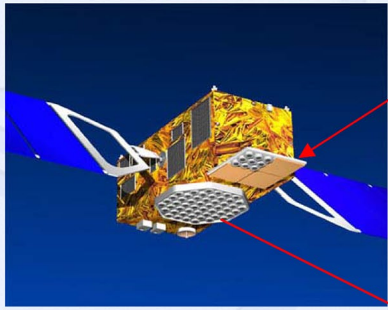
**Transmit effective ionisation parameter in Galileo Navigation message**

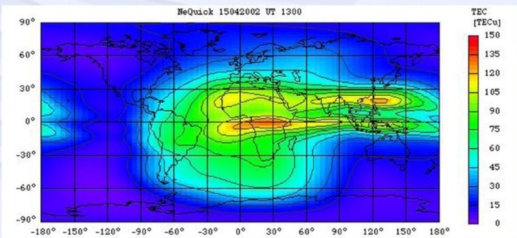
$$Az = a_0 + a_1 \cdot \mu + a_2 \cdot \mu^2$$

*USER RECEIVER*

**Calculate slant TEC using NeQuick with broadcast ionisation parameter. Correct for Ionospheric delay at frequency in question.**

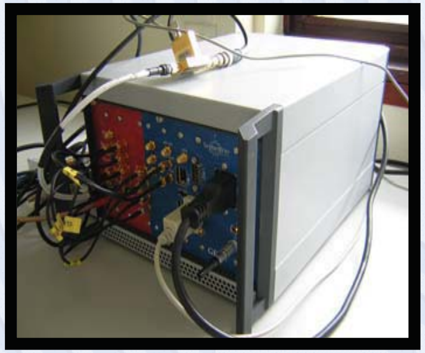







# Examples for Galileo Components

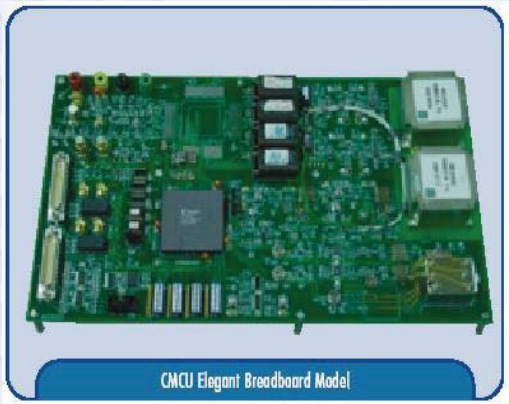

Sensor Station Antenna



Galileo Test Receiver


Signal generator

Galileo Receiver




On-board CMCU


TTC Transponder

# GALILEO Services

# GALILEO Services (1)

- **Open Service**
  - Mass-Market applications not requiring any guarantee
  - Service is free of charge
  - Single or dual frequency receivers

- **Safety of Life Service**
  - Guaranteed service for Safety-of-Life applications
  - Integrity Alerts
  - Requires Certified Receivers

# GALILEO Services (2)

- **Commercial Service**
  - Professional use and guaranteed service
  - Subscription required

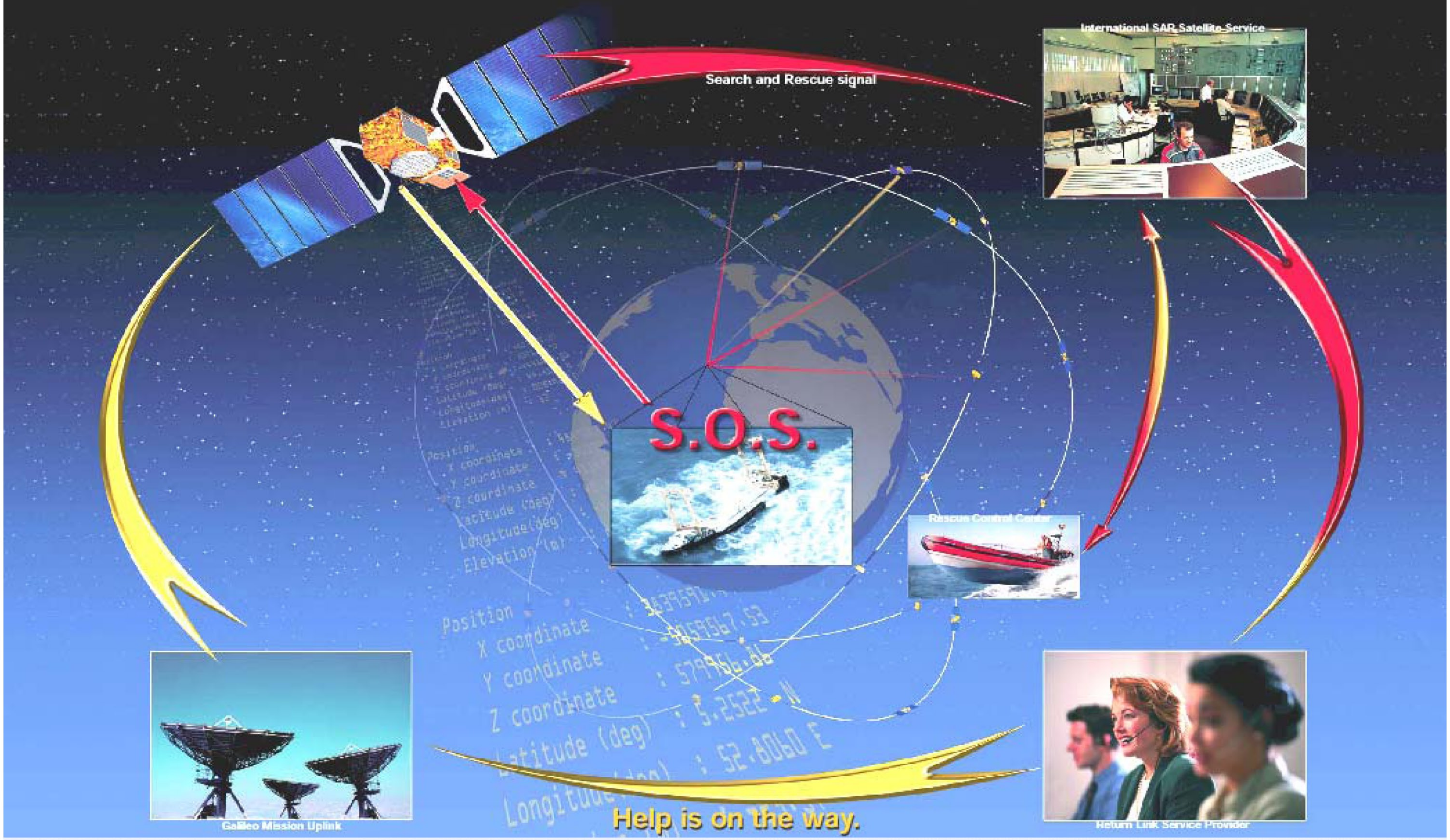
# GALILEO Services (3)

- **Public Regulated Service:**
  - Access limited to government authorized-users.
  - Police, coast guards, customs, strategic civil infrastructure, defense.
  - High continuity of service.
  - Signals more robust to interference.


- **Search and Rescue Service:**
  - Relay of distress alarms to improve existing relief and rescue services.
  - Compatible with COSPAS-SARSAT

# GALILEO SAR

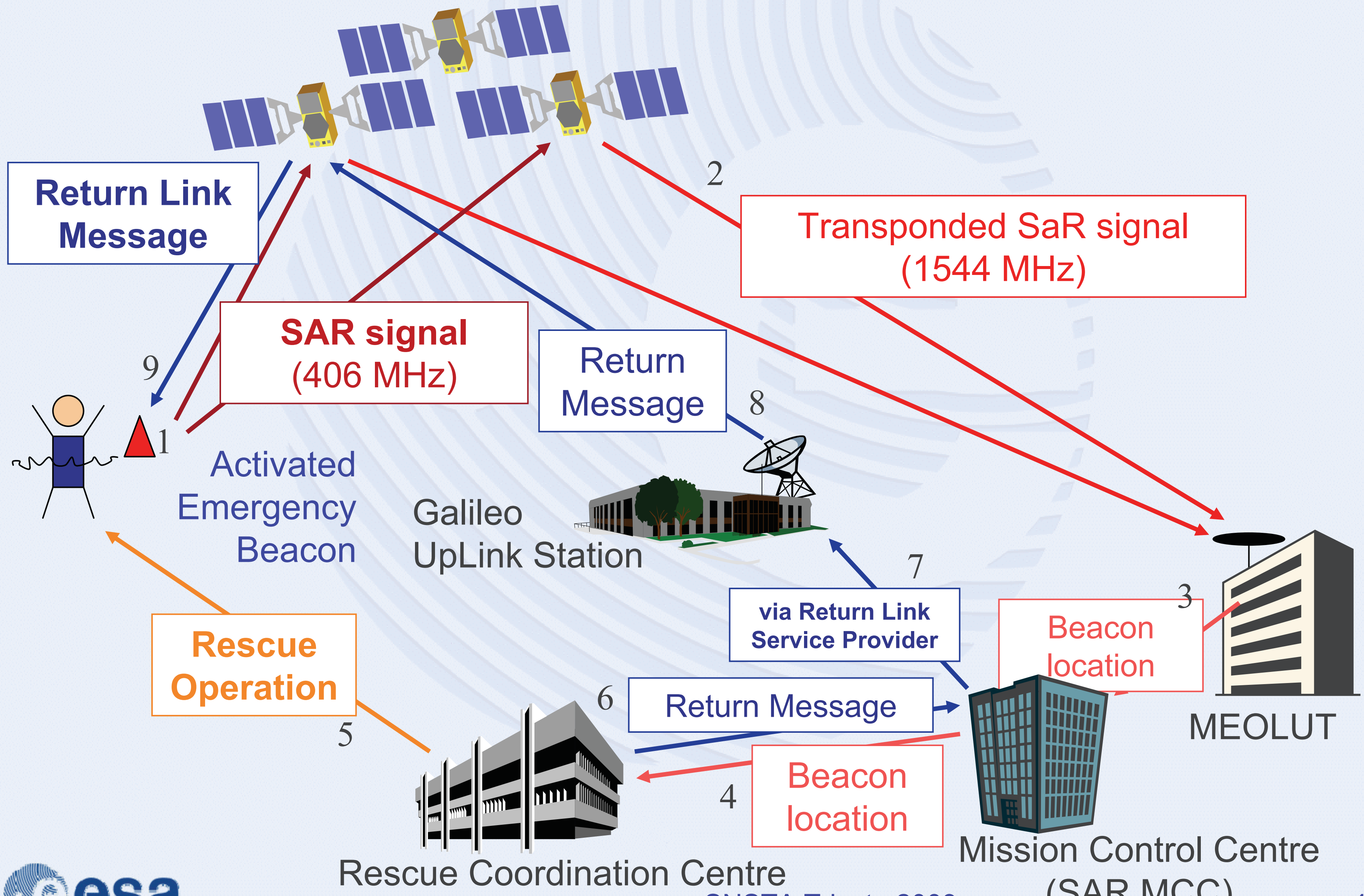
Instantaneous Localisation with Confirmation



# Search & Rescue Mission

- Fulfills the requirements of the IMO (Int'l Maritime Organization) and of the ICAO (Int'l Civil Aviation Organization) for the detection of emergency beacons;
- Is backward compatible with the COSPAS-SARSAT system.
- Reduced detection, localization and confirmation delay;
- Extended distress message with additional information to improve SAR operations;
- Multiple satellite coverage to avoid terrain blockage in severe conditions;
- Increased availability of the space segment;
- New Return Link Service from Rescue Co-ordination Centers to the distress-emitting beacon

# Search and Rescue Architecture



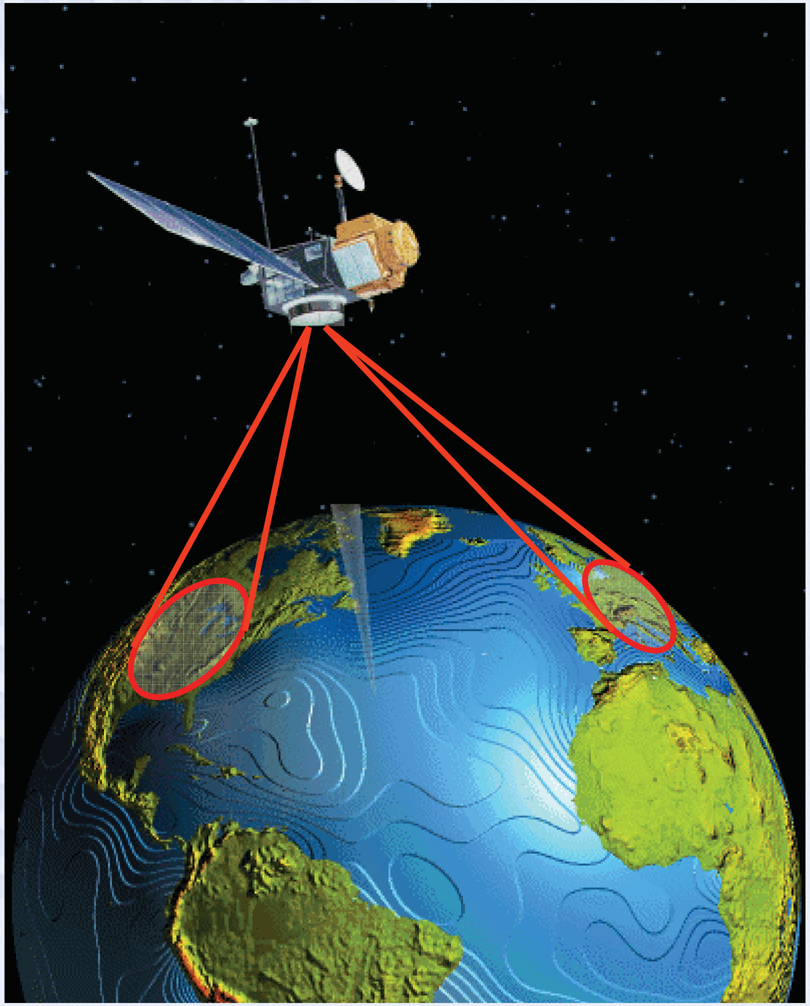
# European GNSS Evolutions Programme

# Programme Objectives

- Prepare for the next generation of EGNOS and Galileo
- Address mission evolution and technology obsolescence
- Address evolution of international regulatory environment and continuous interoperability with other SatNav systems.
- Maintain the necessary know how
- Develop enabling technologies and sustain innovation capabilities.

# Example: Use of C-Band for GNSS

- Could enable improved services
- Available bandwidth is 20 MHz (5010-5030)



# Assessment of the C-Band Satellite-to-Indoor Propagation and Shadowing by Vegetation

- Characterisation and statistical modelling of the environmental effects at C-Band with emphasis on satellite-to-indoor channel and shadowing by vegetation.
- Obtain an experimental dataset, by carrying out a flight campaign with indoor and vegetation measurements.
- Analyze data and develop models for design of systems, devices and impairment mitigation techniques

# GALILEO and the Science Community

# Expectations voiced by Scientists

- Increased number of satellites that can be observed
- Shorter time to first fix
- Better quality of the ephemeris data
- Better quality of onboard clocks and signal generators
- More frequencies used
- Improved gravitational and non-gravitational force models
- Better interaction with the scientific community

# Advisory Groups and Conferences

- ESA has established a GNSS Science Advisory Committee (GSAC) – a group of scientists who are supporting ESA in selecting research activities funded by the GNSS Evolutions programme
- ESA has set up a Conference on the Scientific uses of Galileo
  - 1st Colloquium was held in Toulouse in Oct. 2007
  - 2nd Colloquium will be held in **Padua (Italy) 14 -16 Oct 2009**

http://www.congrex.nl/09c10

# Opportunities for Developing countries

- Science application provide good opportunities to developing countries (if instrumentation is provided by developed countries).
- Participation in measurement campaigns (Ionospheric effects are most severe near the geomagnetic equator) and in the data evaluation and modelling

  Example: LISN network in South America – ESA is considering conducting experiments in Africa

# THANK YOU!