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# Galileo Operational Algorithms Development: Integrity, Orbit Determination and Time Synchronisation

**IGS Workshop 2006**
**May 8-11, ESOC Darmstadt**

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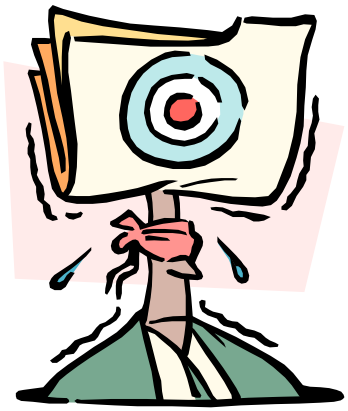
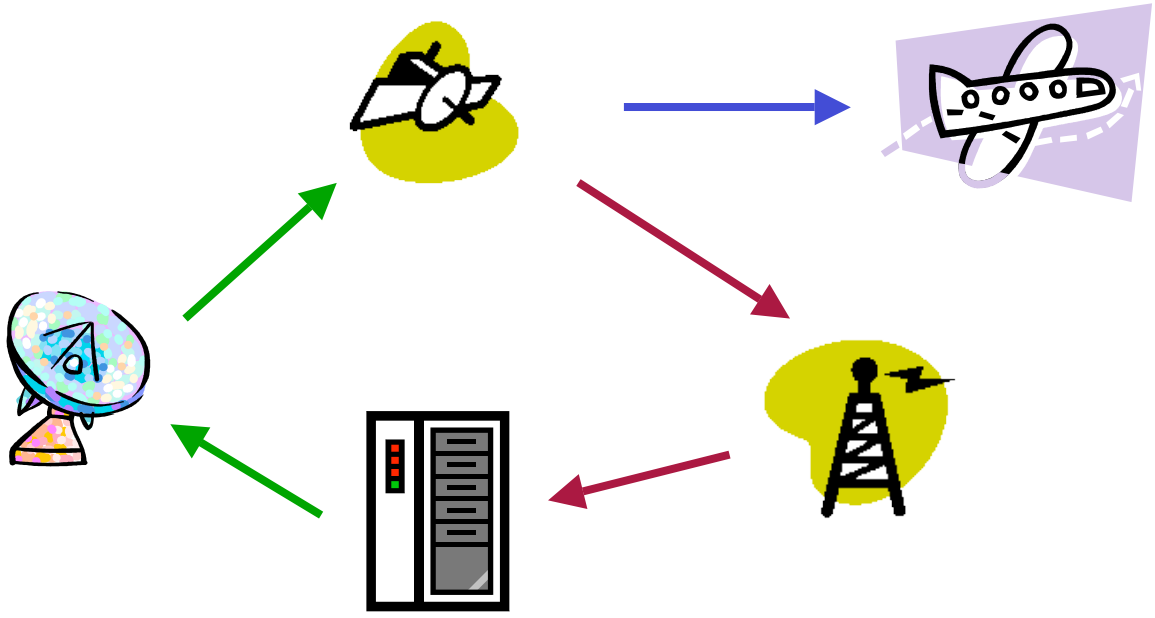
- Introduction
- Galileo Navigation Algorithms
  - Design & Experimentation steps
  - Current Status
- Galileo Integrity Concept
- Galileo Integrity Algorithms
  - Overview & Status
- Summary

- **Navigation Algorithms** generate the information the users need to compute their position and time
  - Satellite orbit and clock offset predictions
  - **Key for Galileo Mission**

- **Integrity Algorithms** generate the information that will allow the users to trust the navigation message and to decide if the system performances fit their needs
  - **Key for Safety-of-Life applications**

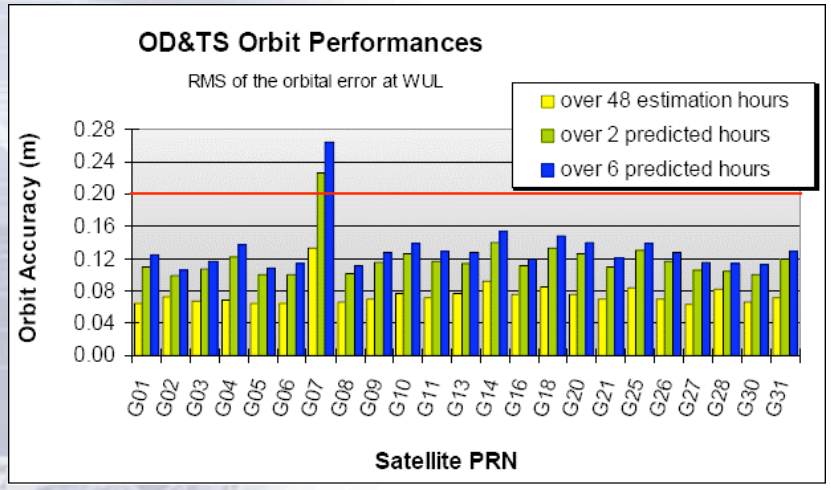


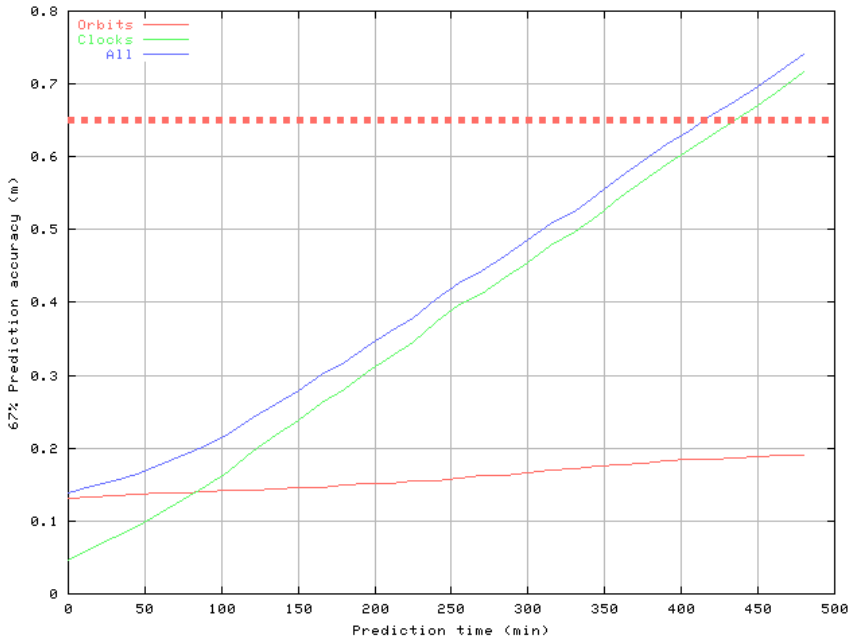
- Galileo Navigation Algorithms will continuously run in the **OSPF**, so that the users always receive valid navigation messages from the satellites
  - OD&TS process
  - Accurate and **reliable (OSPF unmanned)**



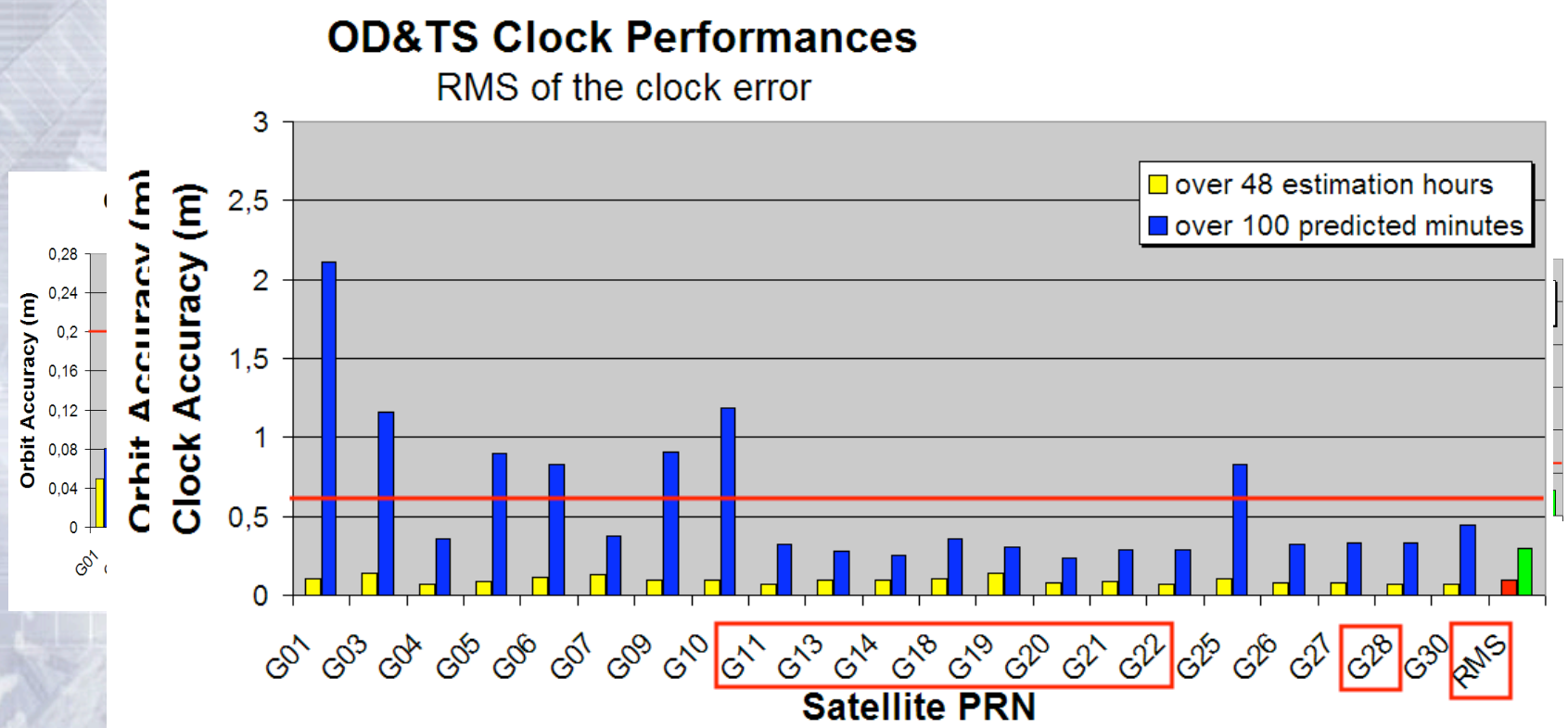
- The Galileo Navigation Algorithms have been defined in the Galileo Definition Phase, including prototyping
  - Accuracy target: 65cm UERE ($1\sigma$)
- Initial studies
  - Based on simulations
  - Trade off between options leading to:
    - On-Ground processing
    - Use of navigation signal
    - Batch processing
    - High-accuracy dynamic and measurement models

- Experimentation with real GPS data and existing SW
  - Trade-offs
  - **Feasibility of targets** (Block IIR clocks)
  - Extensive use of IGS data

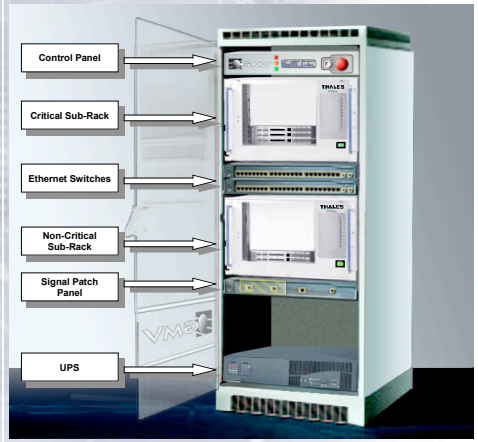


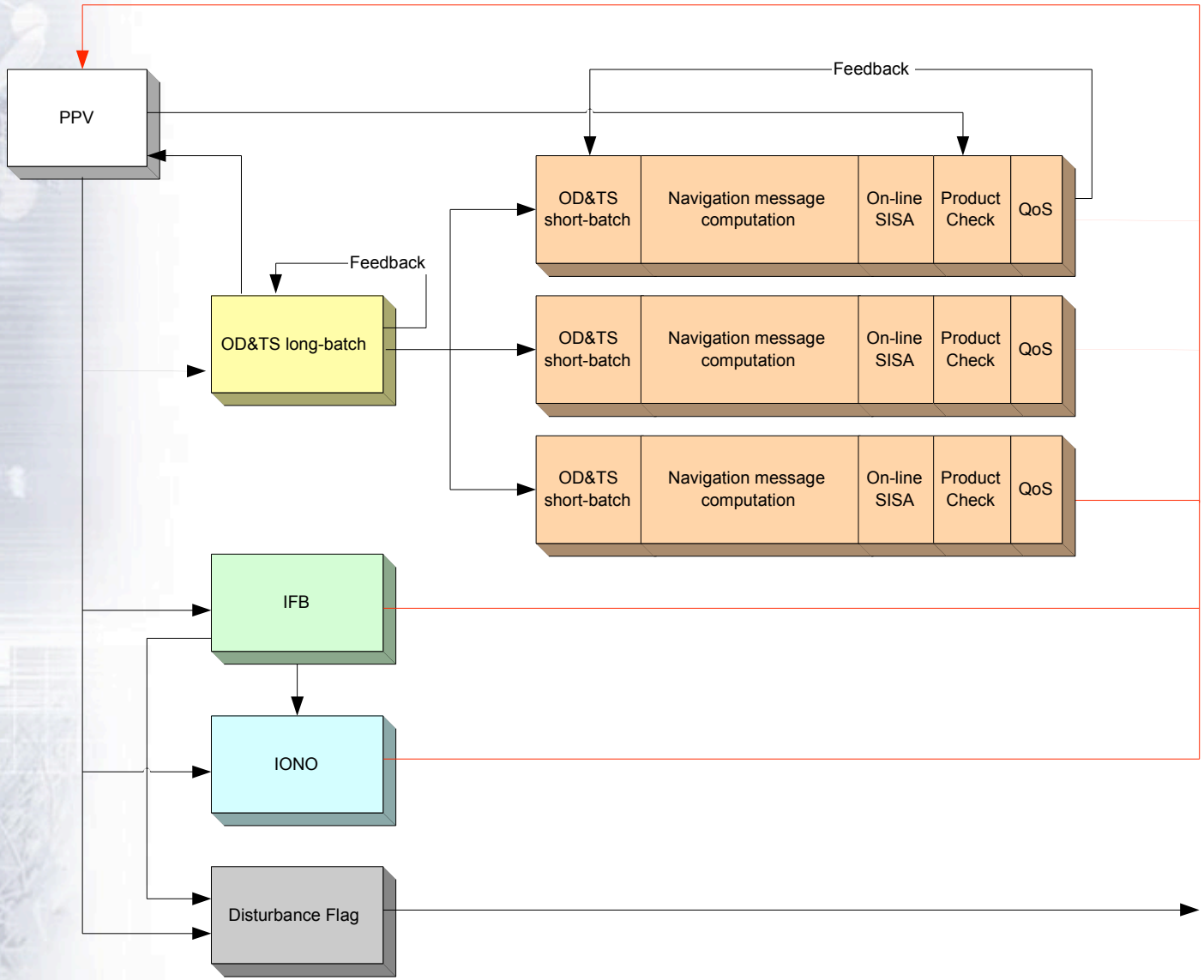
- Additional experimentation cycles



- The OSPF is a real-time facility that performs a number of processes (cont'd):
  - Computation of the BGD parameters (similar to GPS TGDs)
  - Computation of the ionospheric model for single-frequency users (SFIONO+IDF)
  - Navigation data elaboration and product check
  - Generation of Quality of Service (QoS)
  - OSPF Internal Monitoring and Control
  - Generation of technical and mission monitoring data




- The OSPF is a safety-critical element, an overall DAL C level having been allocated to its SW development.
- The HW platform is based on a certifiable VME multi-processor architecture.
- CPU time budget
  - Algorithm modifications: Long and short arcs
- Robustness
  - Barriers against feared events
  - Product Check


PPV
Feedback
OD&TS short-batch
Navigation message computation
On-line SISA
Product Check
QoS
Feedback
OD&TS long-batch
OD&TS short-batch
Navigation message computation
On-line SISA
Product Check
QoS
OD&TS short-batch
Navigation message computation
On-line SISA
Product Check
QoS
IFB
IONO
Disturbance Flag

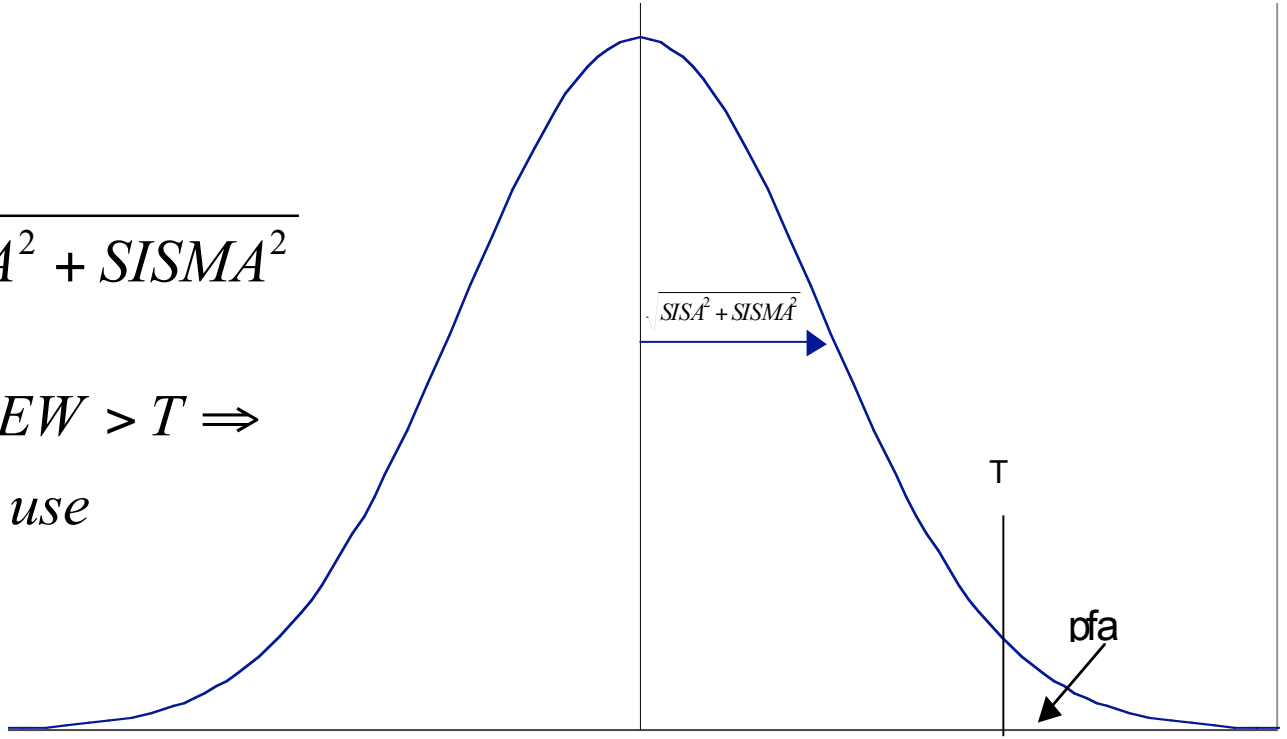
- Satellite broadcast:
  - Ephemeris and clocks
  - SISA (indicator of the accuracy of the navigation data): Fault-Free
  - IF (SISA is valid or not)
    - USE / DO NOT USE the satellite
  - SISMA (indicator of the accuracy of the SISE measurement error associated to the IF computation)
- Users take the SISA / IF / SISMA and compute their **integrity risk** vs alert limit
  - Decide to use or not
  - Not PL Concept (error estimation vs alert limit)

- Real SREW overbounded by N(0, SISA)
- Estimated SREW Error overbounded by N(0, SISMA)
- Estimated SREW overbounded by N(0, $\sqrt{SISA^2 + SISMA^2}$)

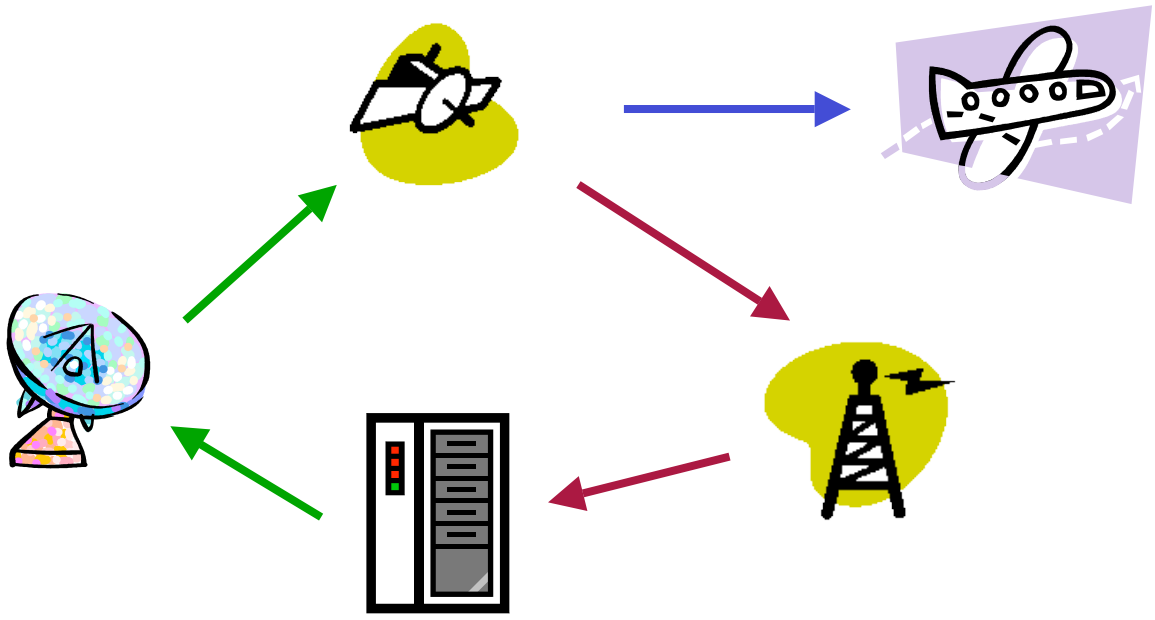
$$T = k_{fa} \cdot \sqrt{SISA^2 + SISMA^2}$$

$$EstimatedSREW > T \Rightarrow$$

$$IF = Do\ not\ use$$

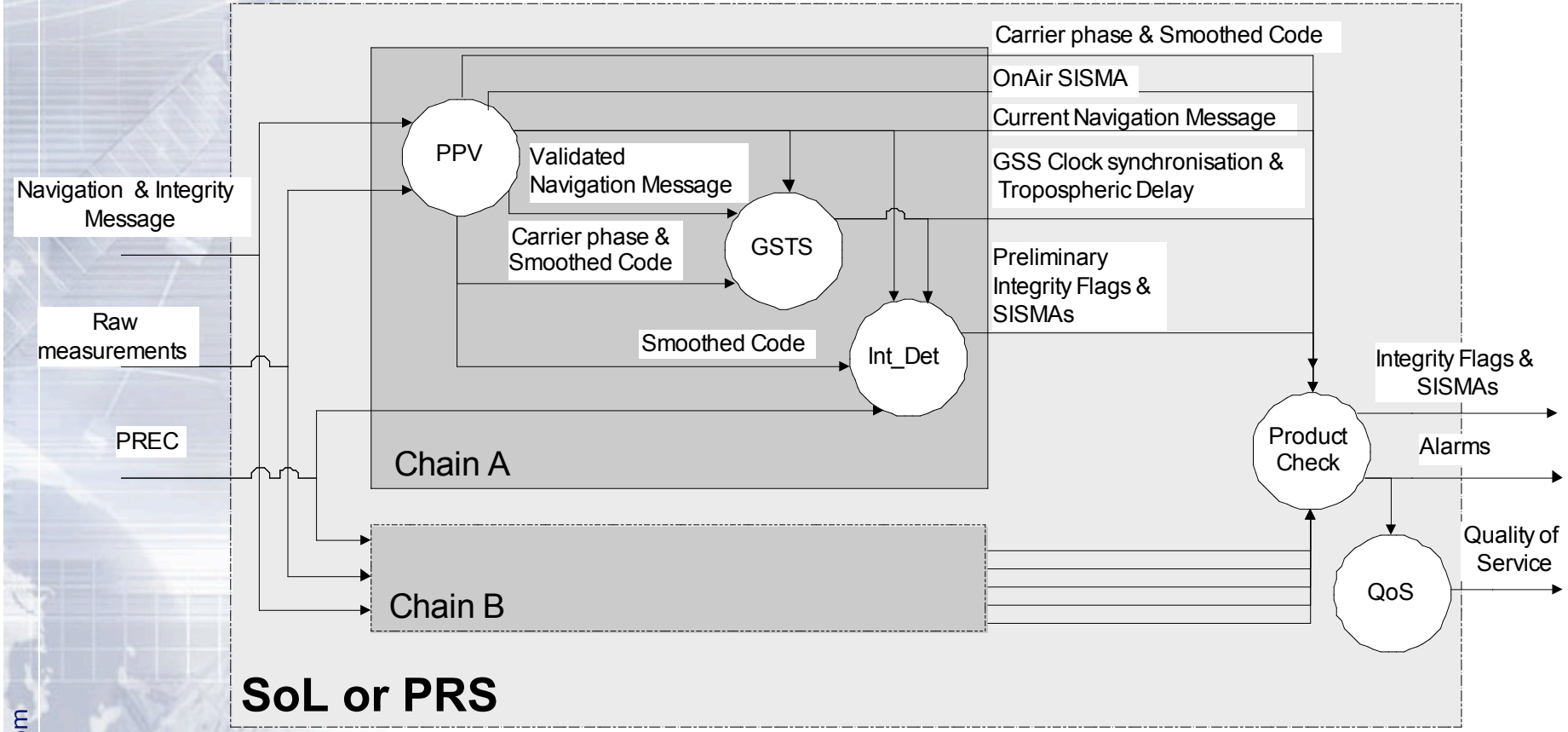


- Galileo Integrity Algorithms will run in real time in the **IPF**, so that the users always receive valid integrity information (IF and SISMA) from the satellites
  - 40 GSS (2 receiver chains each)
  - Fast and **reliable (IPF unmanned)**

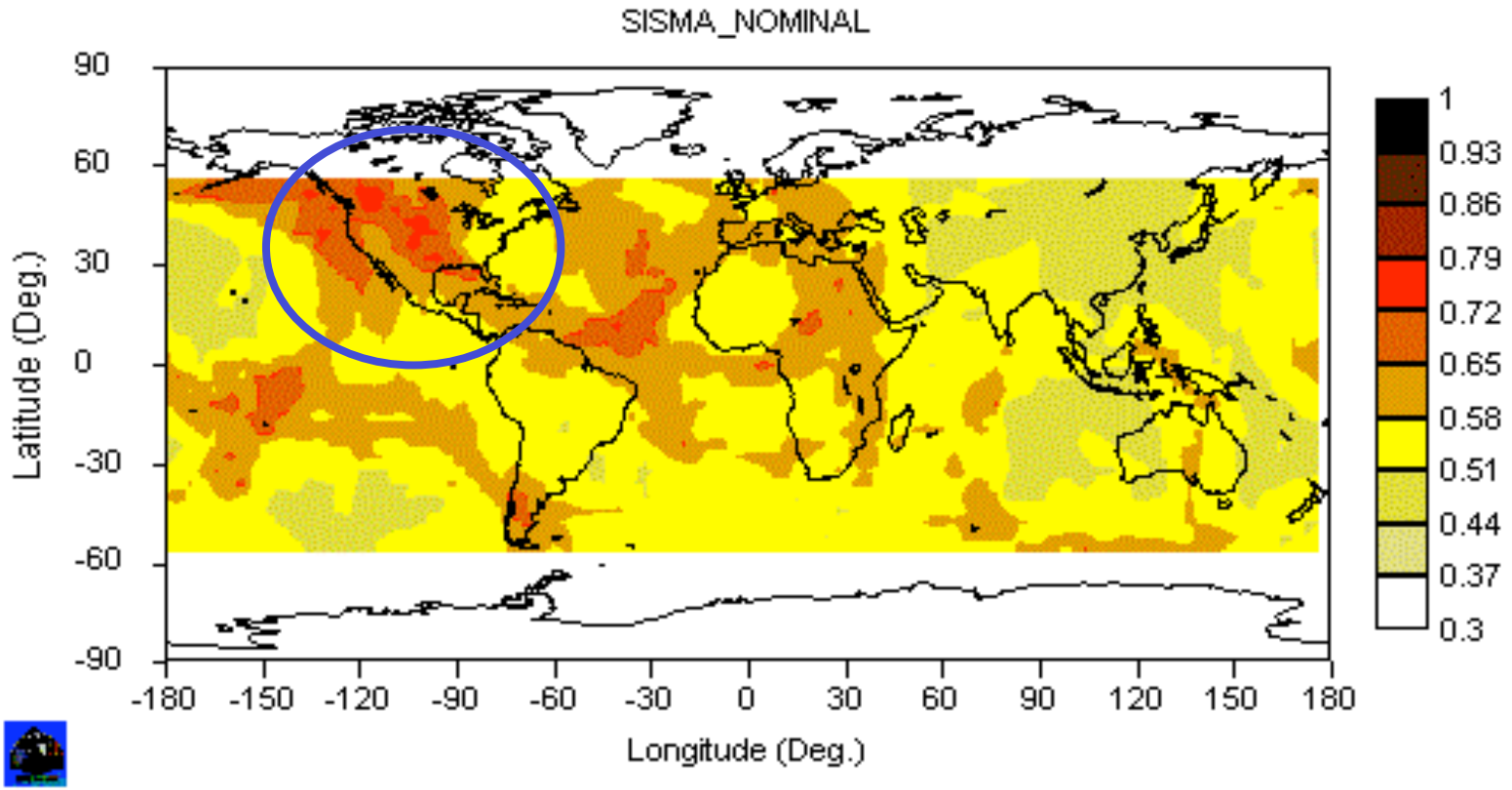


- Navigation and Integrity algorithms are implemented in a safety-critical SW:
  - Navigation -> DAL "C"
  - Integrity -> DAL "B"
- A rigorous SW development process is a must with a special emphasis on the verification activities and RAMS aspects:
  - Analysis of failure modes
  - Minimisation of single point of failures
  - Independent SW verification for DAL B
  - Extensive unit, integration and system testing
- The implementation of the algorithms may be constrained by the SW development rules (E.g.: deterministic behaviour, maximum CPU time shall be known, etc.)

- The selection of the HW platform is strongly constrained:
  - Reliability
  - Robustness
  - Provision of Built-In-Test
  - Maintainability (during the whole Galileo lifetime)
  - Certifiability
  - …
- This implies a reduction in the CPU power and RAM memory available w.r.t. the standard workstations:
  - Single processor boards
  - Up to 2 Gb of RAM memory
  - Pentium-M processors (1.6-1.8 GHz)


Carrier phase & Smoothed Code
OnAir SISMA
Current Navigation Message
GSS Clock synchronisation & Tropospheric Delay
Navigation & Integrity Message
PPV
Validated Navigation Message
GSTS
Carrier phase & Smoothed Code
Preliminary Integrity Flags & SISMAs
Raw measurements
Smoothed Code
Int_Det
Integrity Flags & SISMAs
PREC
Product Check
Alarms
Chain A
Quality of Service
QoS
Chain B
SoL or PRS

- Degree of coverage of the GSS network widespread over the world, so the better the geometry the better the performance
- Quality of the raw measurement data provided by the GSS, basically the receiver noise, interference and multipath
- **Quality of the synchronization and tropospheric delay estimation processes**




- SISMA target = 0.7 m

- The status of the Galileo Navigation Algorithms has been presented
  - Quite mature state
  - Feasibility of performance targets
  - Robustness
  - Operational Constraints
- The status of the Galileo Integrity Algorithms has been presented
  - Challenging requirements
  - Improvements on-going
  - Promising performances