UTC Leap Seconds and Galileo

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European Space Agency

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Galileo Timing User specs

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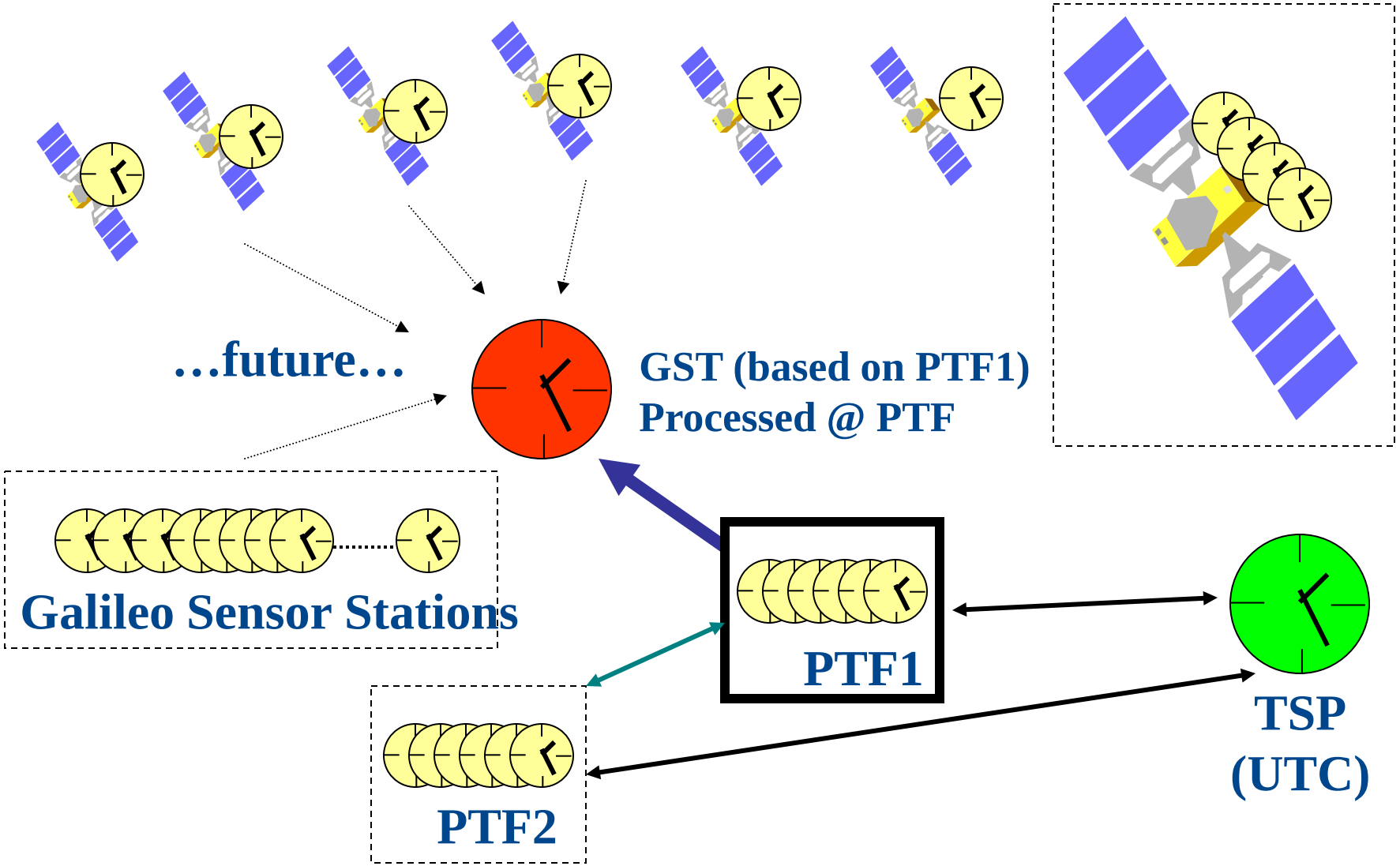
User Performance	Specification
Frequency Accuracy (expressed as a normalised frequency offset relative to UTC, 2 sigma, over any 24 h interval)	$< 3 \times 10^{-13}$
User UTC determination uncertainty (2 sigma)	< 30 ns

Setting-up Galileo System Time



PTF-Precise Timing Facility TSP-Time Service Provider

Navigation and Metrological Timekeeping

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Precise Timing Facility (PTF) — Core System

- **Navigation Timekeeping – critical for navigation**
  - Stable and autonomous timescale
  - Synchronisation of ground facilities
  - Reference for satellite orbit and clock prediction
  - Internal time tagging

- **Metrological Timekeeping – necessary for Galileo Timing Service**
  - Accurate timescale synchronised to UTC (modulo 1 second)
  - Implementation of ITU recommendations
  - (Legally) valid time-tagging of user position and time
  - Timing service for specialised users

Time Service Provider — External

Definition of Galileo System Time (GST)

Galileo System Time (GST) shall be a continuous co-ordinate time scale in a geocentric reference frame, steered towards the UTC modulo 1 second.

GST start epoch: 00:00 on Sunday August 22nd 1999 (midnight between August 21st and 22nd). At the start epoch, GST shall be ahead of UTC by thirteen (13) leap seconds.

GST-UTC = 16 s (as of 01/07/2012)

GST format as broadcast in the satellite navigation message

- Week Number (WN)
- Seconds of Week

GST and GPSTime:

- GST-UTC = GPST-UTC
- WN(GST) = WN(GPSTime(w. roll-over)) - 1024
- Seconds of Week (GST) = Seconds of Week (GPSTime)

Galileo System Time vs. UTC mod 1 sec

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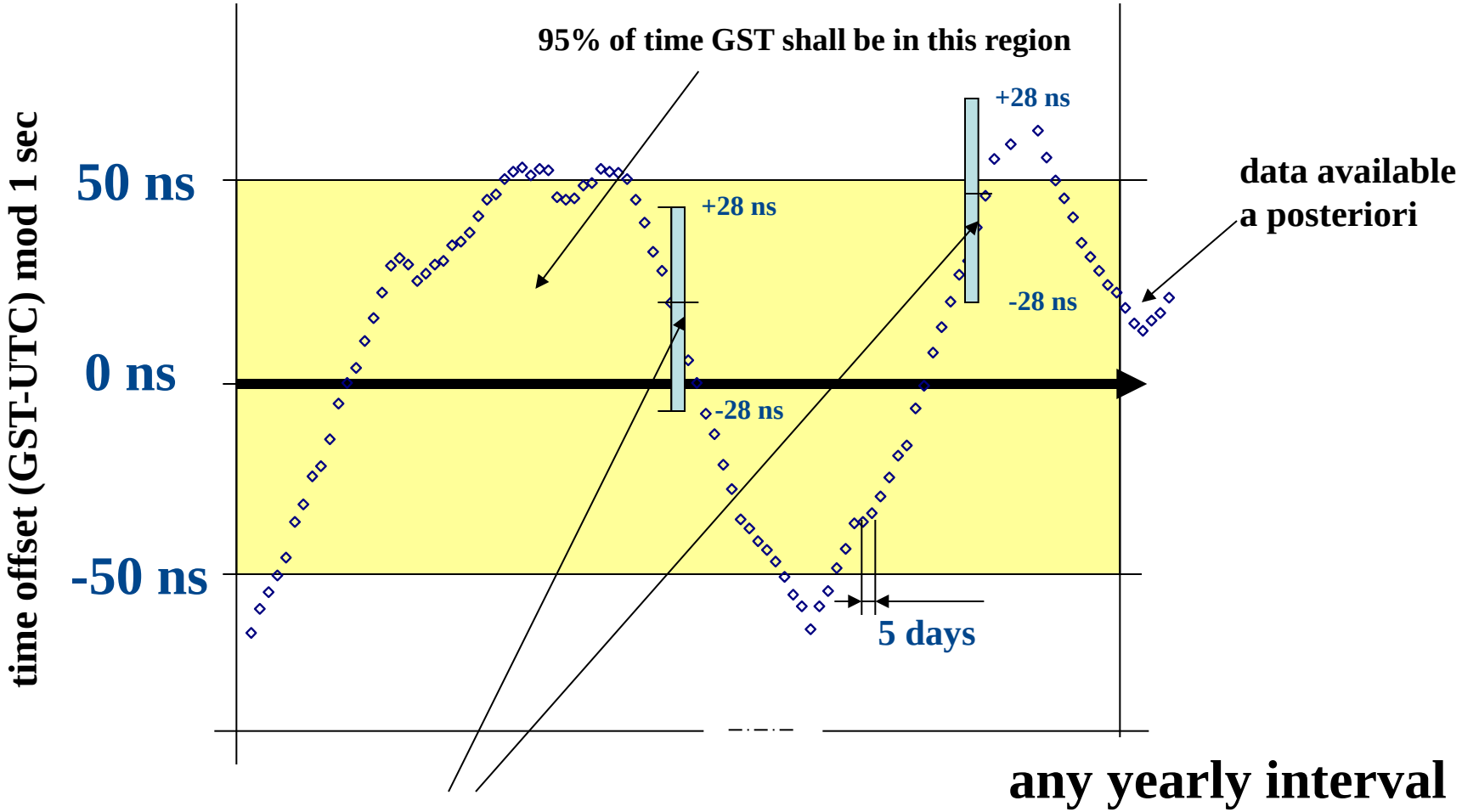

Galileo vs. BIPM, USNO, GPS

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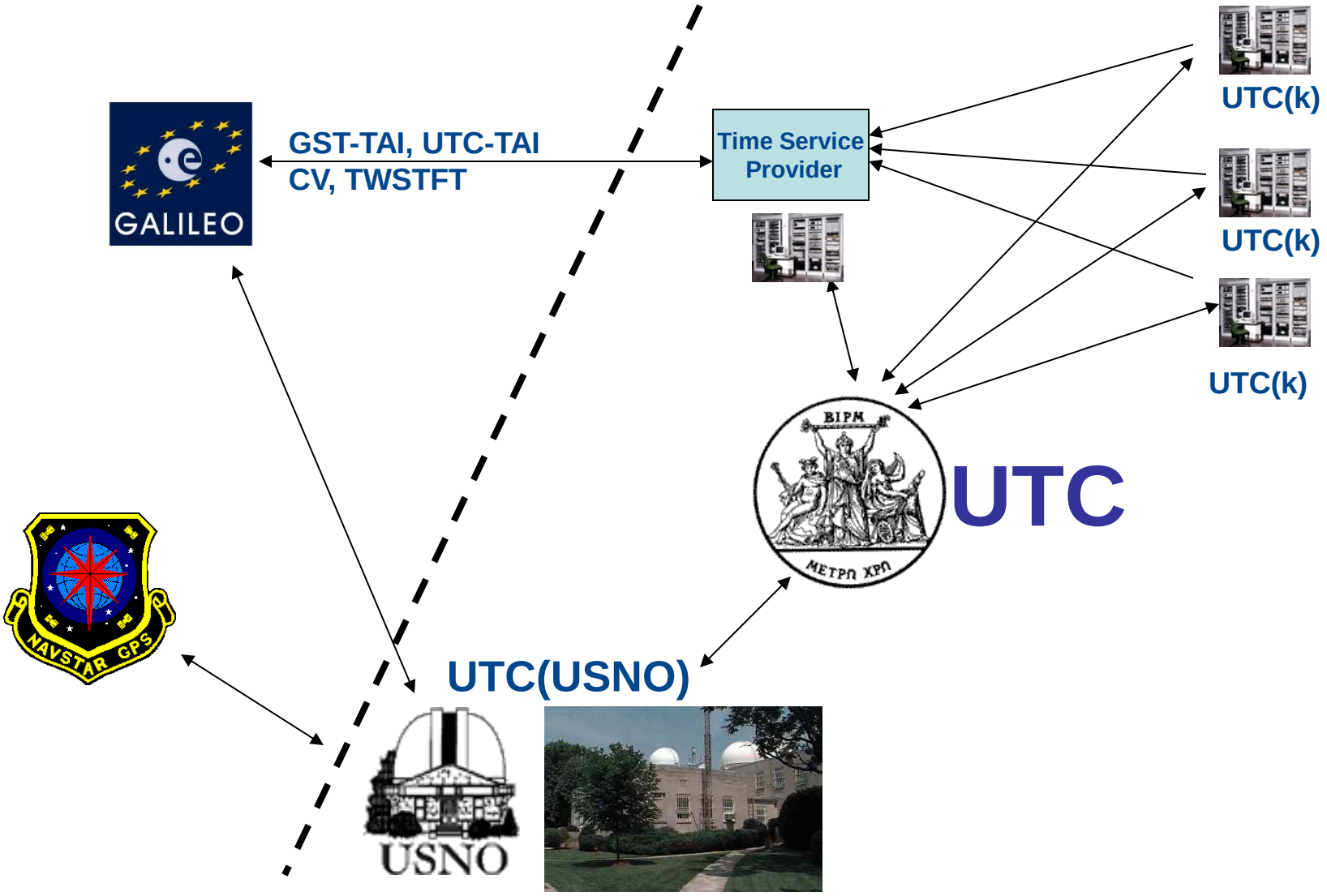

Task of the Precision Timing Facility

PTF Mission

- Generate and distribute physical representation of GST

PTF Objectives

- Generate GST timescale from a clock ensemble
- Generate physical realisation of GST timescale
- Distribute GST externally and within Control Center (GCC)
- Ensure steering of two GST timescales at two GCCs
- Contribute to GST steering to UTC
- Compute GPS to Galileo Time Offset
- Support Ground Segment for timing mission monitoring

Tasks of the Time Service Provider

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The external Time Service is in charge of:

- **Operating the daily links to UTC(k) laboratories required for the determination of UTC, the periodic calibration of the equipment and remote control facilities, etc.;**
- **Performing the data analysis of all the measurements GST-UTC(k);**
- **Monitoring GST performance through the Signal-in-Space**
- **Developing and operating the UTC_p prediction algorithm;**
- **Providing Galileo with the daily predicted value of (UTC_p-GST) time and frequency offset and the daily steering correction;**
- **Interfacing with the BIPM by sending the internal clock data and GST-UTC(k) and receiving from BIPM the Circular T ($GST\text{-}UTC(k)_{old}$);**
- **Providing data exchange under request from Galileo Control Segment (TWSTFT and CV);**
- ***Provision of an opportunity for an extended scientific activity, in collaboration with the leading laboratories, for obtaining an improved accuracy of GST (better than the specifications) and matching the present and future accuracy targets***

NOTE: Currently the TSP function is operationally fulfilled by the Time Validation Facility (TVF) until TSP is in place.

Tasks of the Time Service Provider (cont'd)

NOTE: Currently the TSP function is operationally fulfilled by the Time Validation Facility (TVF) until TSP is in place.

UTC(k) laboratories contributing to TVF IOV:

PTF in Galileo Control Center (Fucino)

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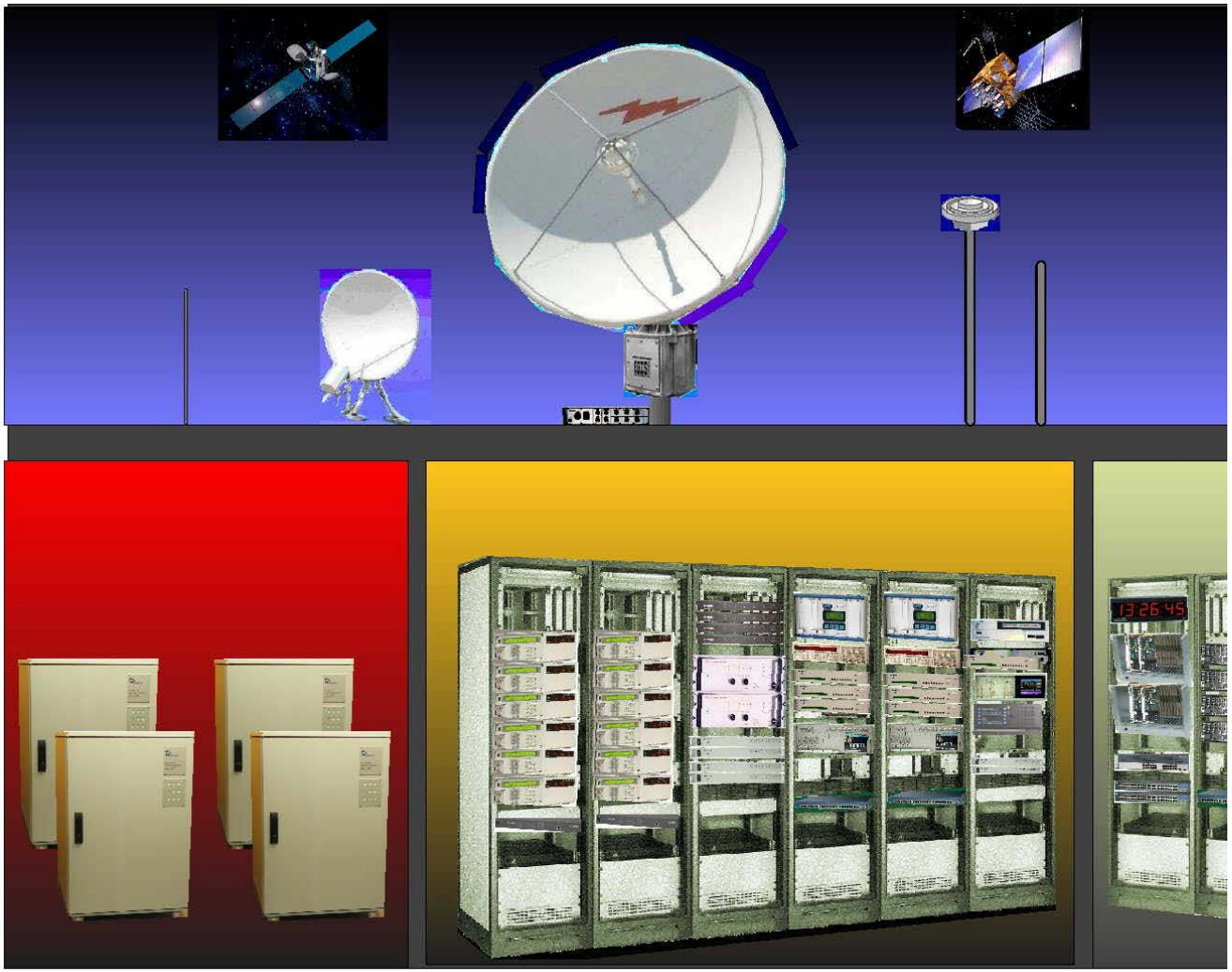

Controlled environment (+/- 0.1ºC)

Computer room

Access to GST

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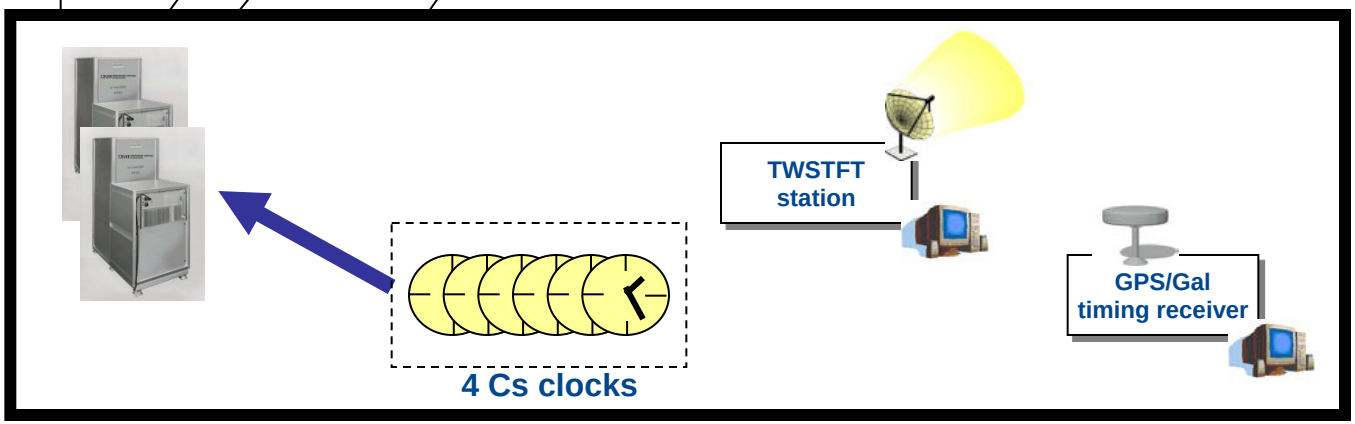
Internal use:

1 pps
10 MHz

PHYSICAL OUTPUT

Pseudo-Range referenced to GST
TWSTFT and Common View data
Time codes



User access:

via SIS

Timing Service

GNSS CV data
TWSTFT data

Galileo System Time Realisations

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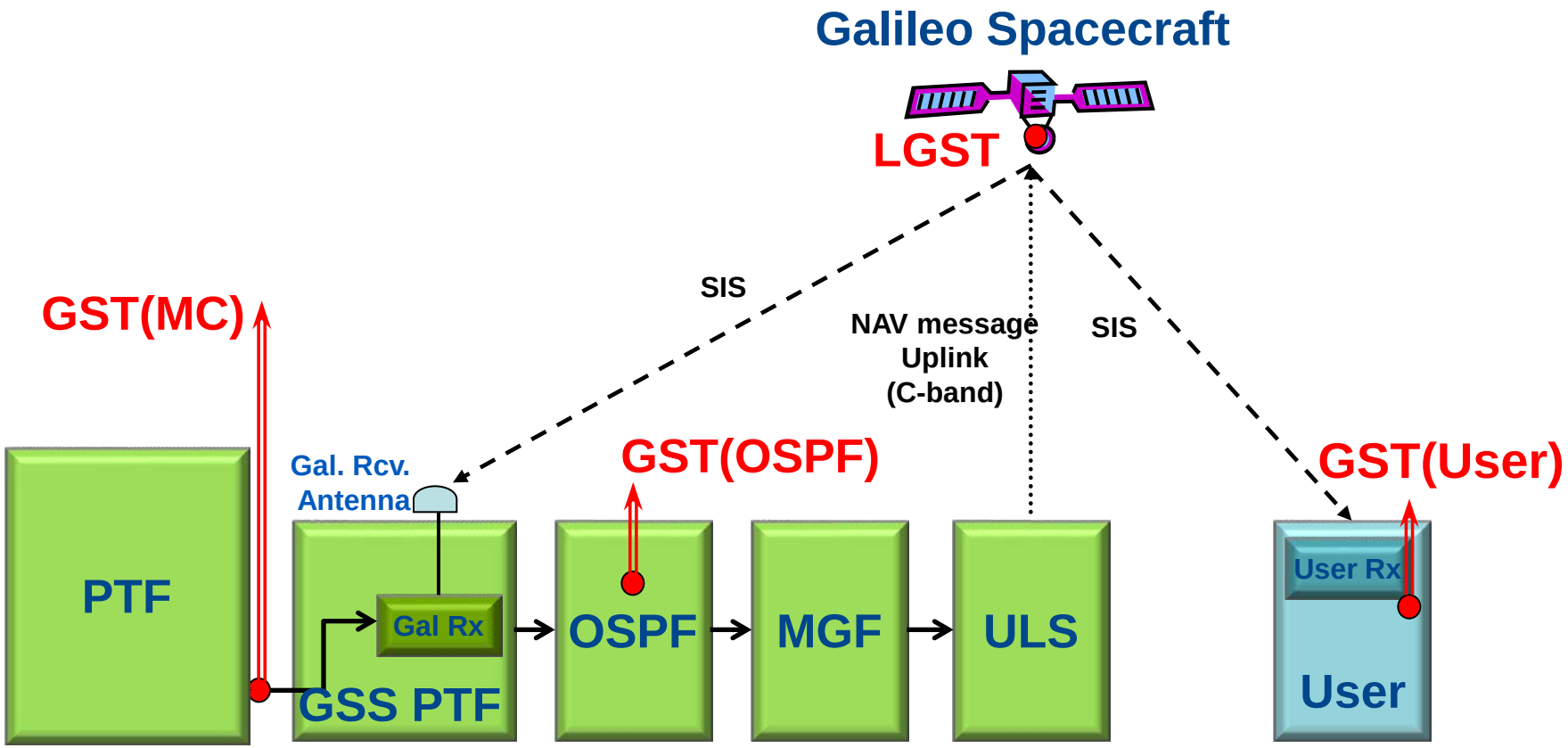
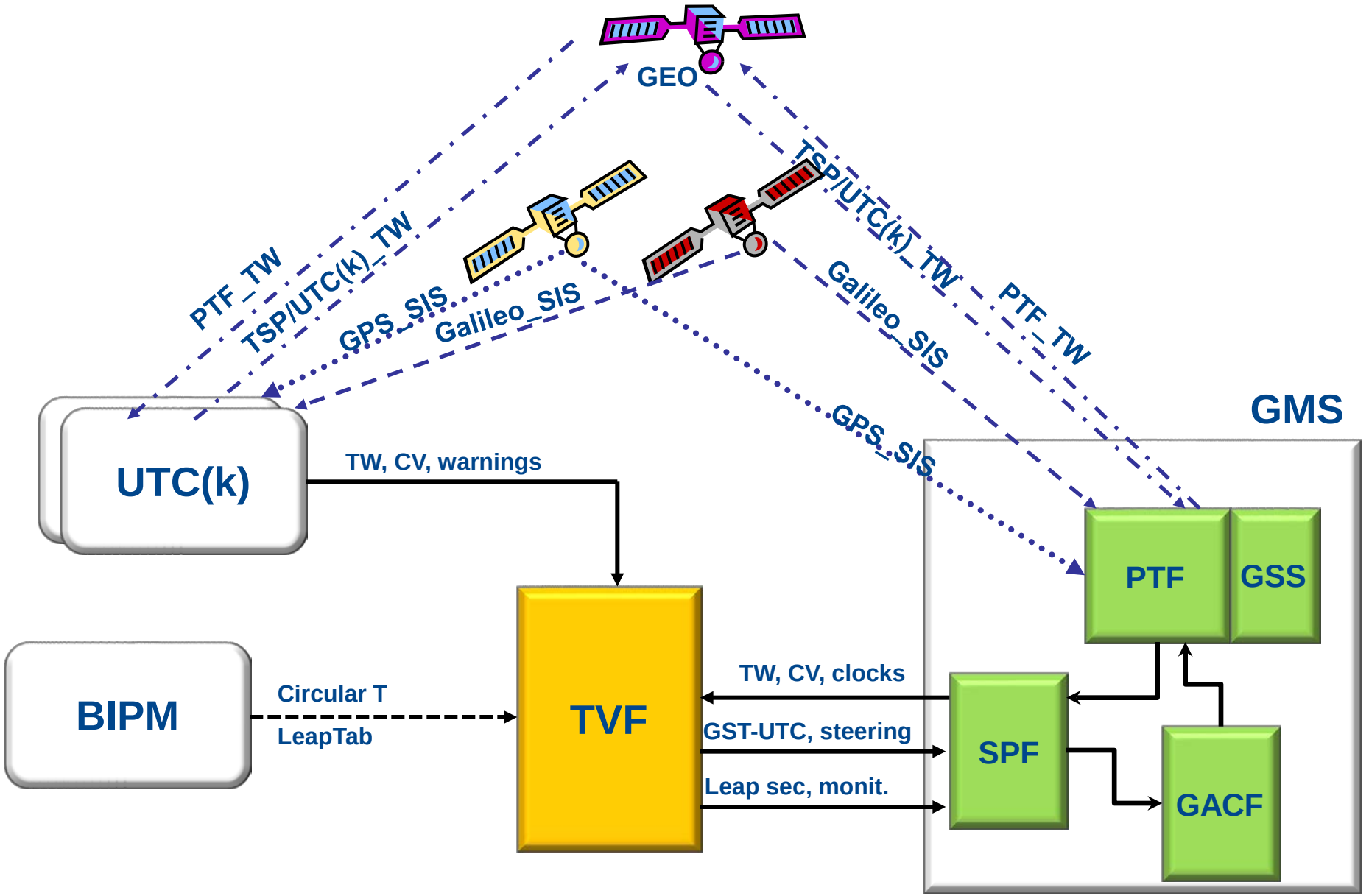


GMS – TVF interface



UTC(k) and UTCpredicted vs. GST (MC)
Early Results

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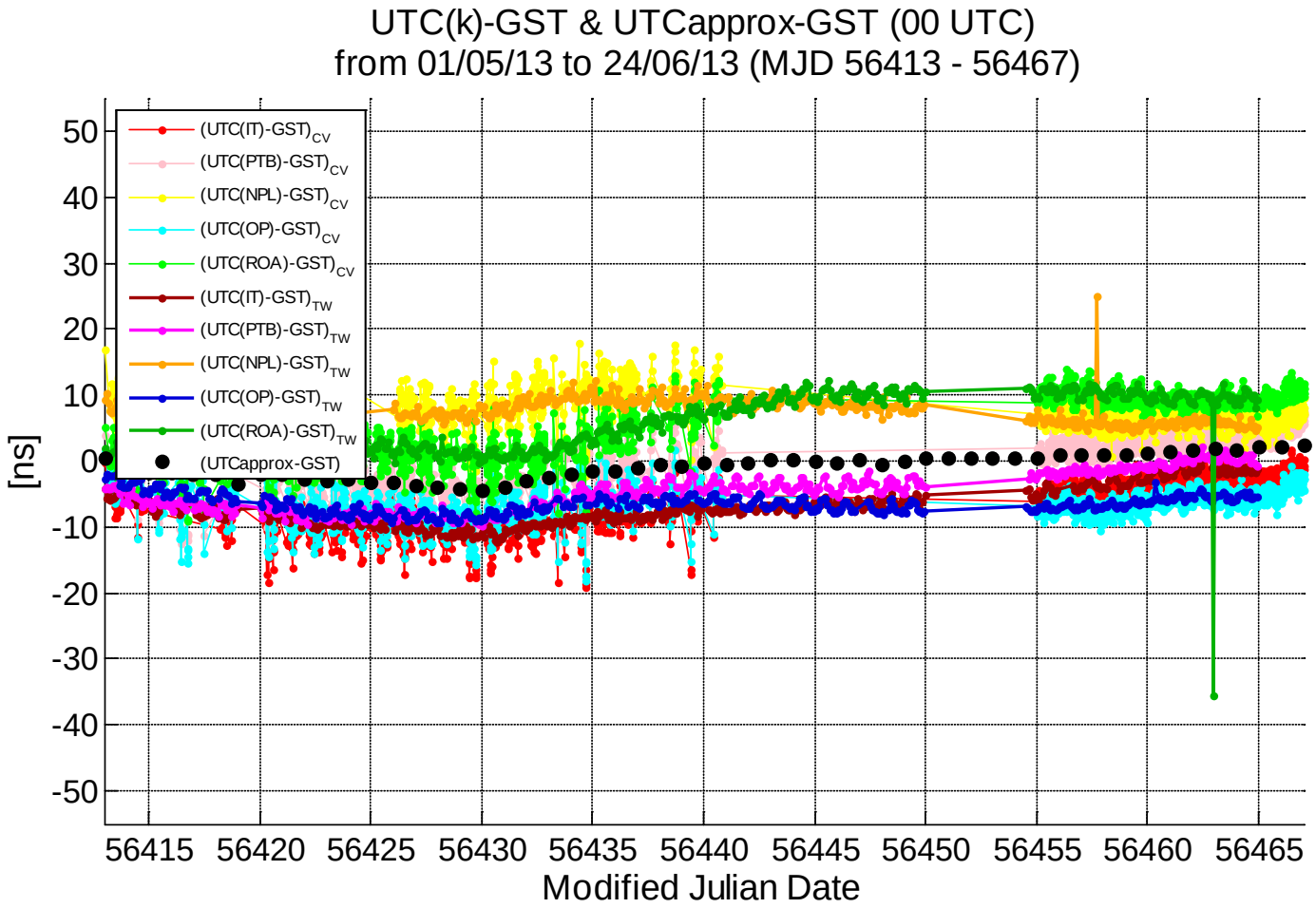
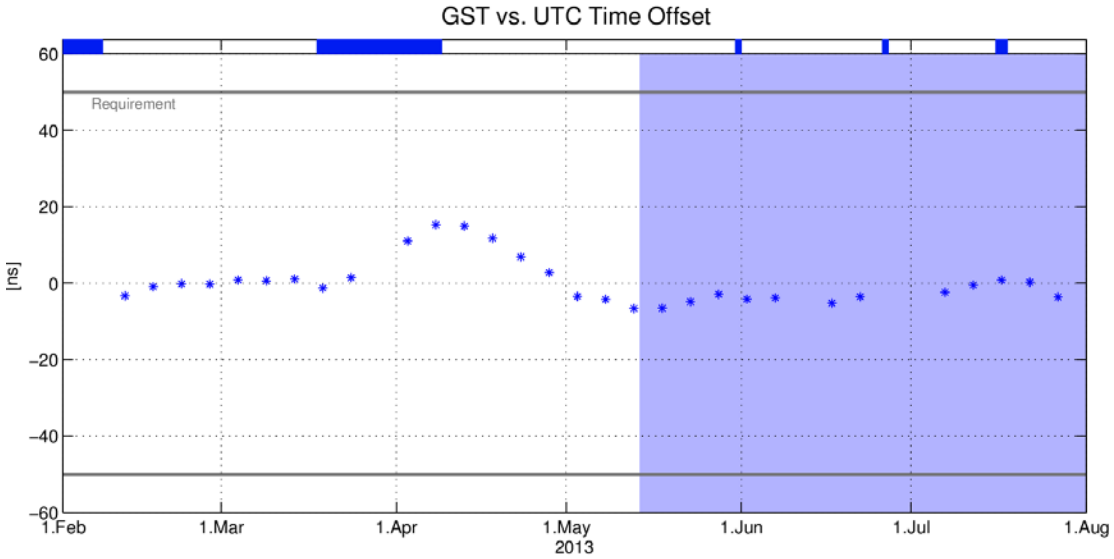
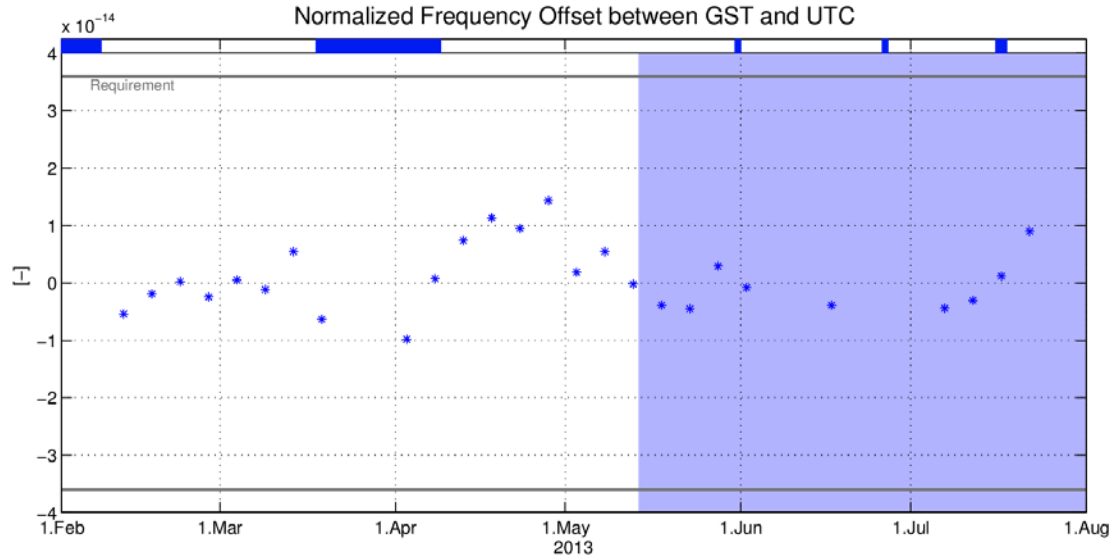


The plot shows daily average of GST(MC) offset to the national real-time realizations of UTC, named UTC(k). The offset UTC(k)-GST(MC) is measured using TWTFT and GPS CV techniques. The real time approximation of UTC named UTCapprox is the average of the five UTC(k)'s predicted vs UTC.

UTC-GST(MC) Time and Freq. Offset
Early Results





- UTC-GST(MC) offset is evaluated monthly using BIPM Circular T
- The period of the IOV campaign is highlighted with the blue shaded area

UTC-GST(MC) Prediction Error
Early Results

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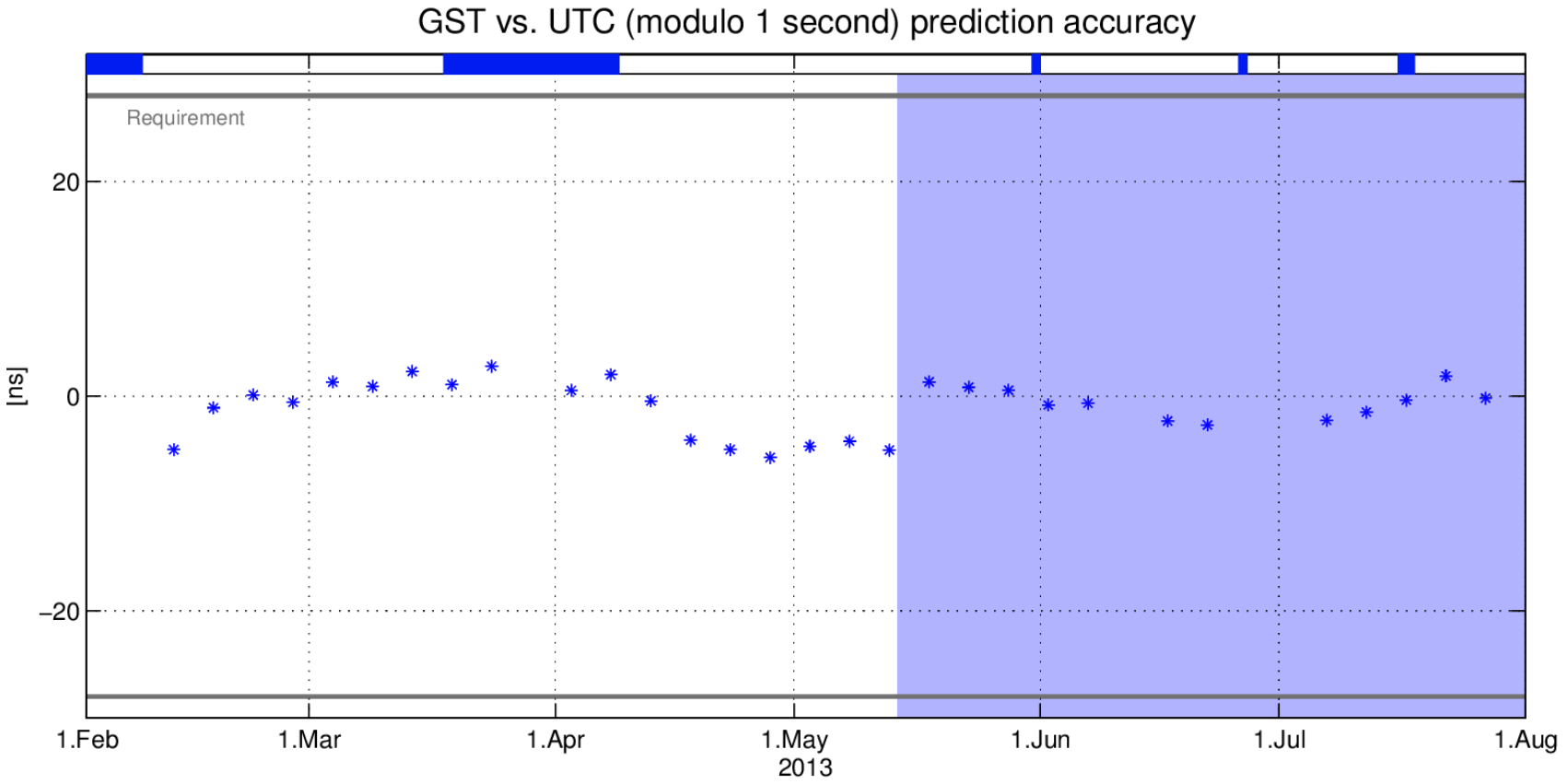

- TVF daily evaluates a prediction value for UTC-GST(MC) time offset. The prediction is broadcast in the Galileo navigation message.
- The UTC-GST(MC) prediction error is evaluated by TVF monthly when CircularT is available.
- Through-out the IOV campaign, UTC-GST(MC) prediction error remains within +/- 5 ns

UTC Dissemination through Galileo

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- **ITU Recommendation 460-4, point 1:**
  - all standard-frequency and time-signal emissions conform as closely as possible to Coordinated Universal Time (UTC)…
- **Galileo provides both precise positioning and timing capabilities (UTC dissemination)**
- **In all its services, Galileo broadcasts conversion parameters between its internal timescale GST and UTC (but not DUT1)**

Parameter	Definition	Bits	Scale factor	Unit
A_0	Constant term of polynomial	32*	2^{-30}	s
A_1	1st order term of polynomial	24*	2^{-50}	s/s
Δt_{LS}	Leap Second count before leap second adjustment	8*	1	s
t_{0t}	UTC data reference Time of Week	8	3600	s
WN_{0t}	UTC data reference Week Number	8	1	week
WN_{LSF}	Week Number of leap second adjustment	8	1	week
DN	Day Number at the end of which a leap second adjustment becomes effective	3	1	day
Δt_{LSF}	Leap Second count after leap second adjustment	8*	1	s
	GST-UTC Conversion Parameters	**99**		

Leap Second in Galileo: Summary

- Different time scales are used within different parts of the system: GST is the internal continuous time reference for the core infrastructure and UTC is the legal time
  - Galileo core infrastructure is synchronised to GST, the data are time tagged also with GST unless prescribed otherwise by international standards (e.g. time transfer data, predicted orbits etc)
  - Galileo satellite on-board timescales are synchronised to GST
  - Galileo Launch and Early Orbit Phase (LEOP) infrastructure and LEOP Control Center are synchronized to UTC
  - Galileo operators will widely use UTC
  - Galileo External Service Providers are synchronised to UTC
  - Galileo users utilise UTC and local time
- Correct GST-UTC conversion (i.e. # of leap seconds) is crucial for Galileo operations. Conversions are either automatic or manual (done by operators).
- Dedicated leap second introduction test will be performed to validate the implementation.
- However, every time a new leap second is introduced, there is a risk of failure!
  - Galileo has correctly handled the leap second 30 June 2012

Impact at Galileo Users

- If leap second introduction is discontinued and UTC-UT1 exceeds 1s, Galileo navigation and timing capability is not effected except for specialised applications relying on close alignment of UTC and UT1.

- DUT1 is currently not included in the navigation message.

- In case, the leap second introduction is discontinued, Galileo may consider provision of DUT1 as per ITU Recommendation 460-4, point 2:

  standard-frequency and time-signal emissions, and other time-signal emissions intended for scientific applications (with the possible exception of those dedicated to special systems) should contain information on the difference between UT1 and UTC

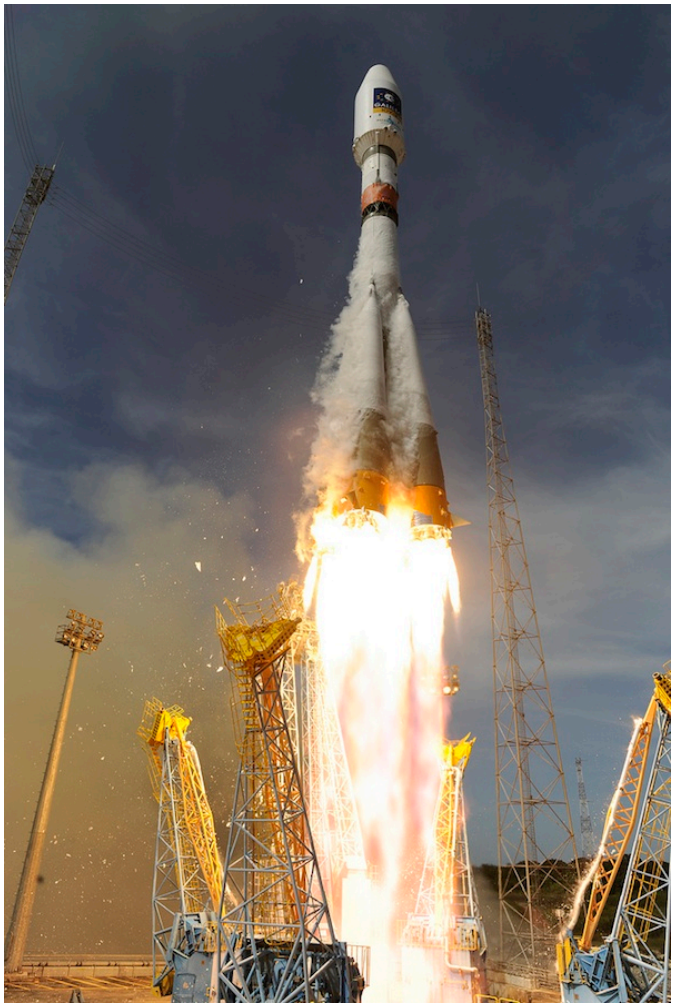
Galileo Position

- Galileo System Time is a continuous coordinated timescale, steered to UTC modulo 1 second. GST-UTC transformation parameters (including leap seconds) are provided in the Galileo navigation message.

- **However, introduction of the leap second is undesirable from the point of view of System Operations.**

- **Once standardisation of the new UTC definition will be in place, an update of Galileo interfaces would be needed.**

- **In any case, Galileo will follow international standards and recommendations.**



http://www.esa.int/Our_Activities/Galileo

http://ec.europa.eu/galileo