Proba-3 Precise Orbit Determination based on GNSS observations

W. Enderle, F. Gini, E. Schönemann, V. Mayer, M. Otten

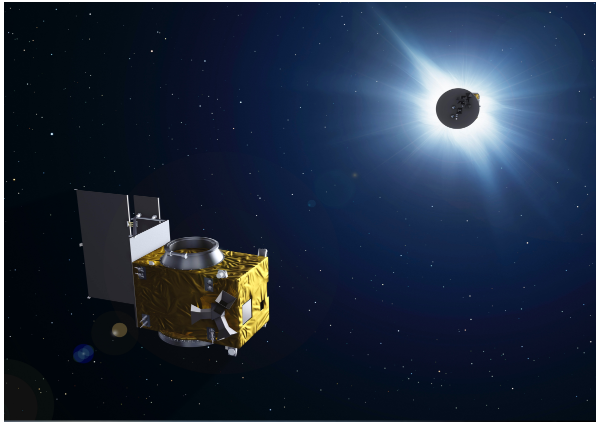
04/01/2019 Breckenridge, CO, USA

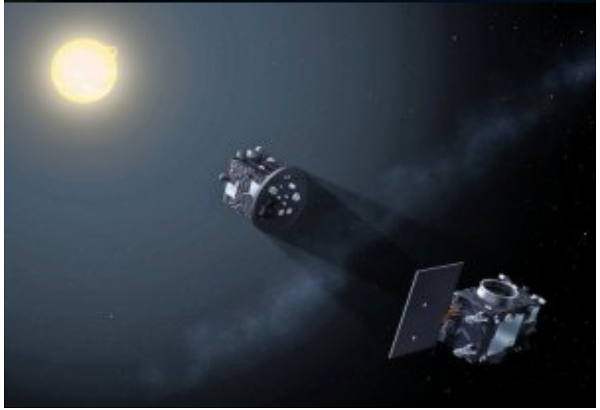
Outline

- Introduction and Motivation
- GNSS signal availability simulations setup: orbital and link-budget parameters
- GNSS signal availability results
- POD setup: observations and dynamical parameters
- POD results
- Conclusions

Introduction and Motivation

- ESA’s PROBA-3 mission is a Technology Demonstration Mission for high-precision formation-flying of a pair of satellites in an HEO orbit with new developed technologies
- The launch of the spacecraft is expected in late 2020. The PROBA-3 spacecraft pair will fly divided between periods of accurate formation flying, when payload observations will be possible, and periods of free flight
- PROBA-3 will fly above the GNSS constellations, therefore an analysis is conducted to evaluate the GNSS signals availability in the Space Service Volume (SSV) and its impact on the Precise Orbit Determination (POD) accuracy

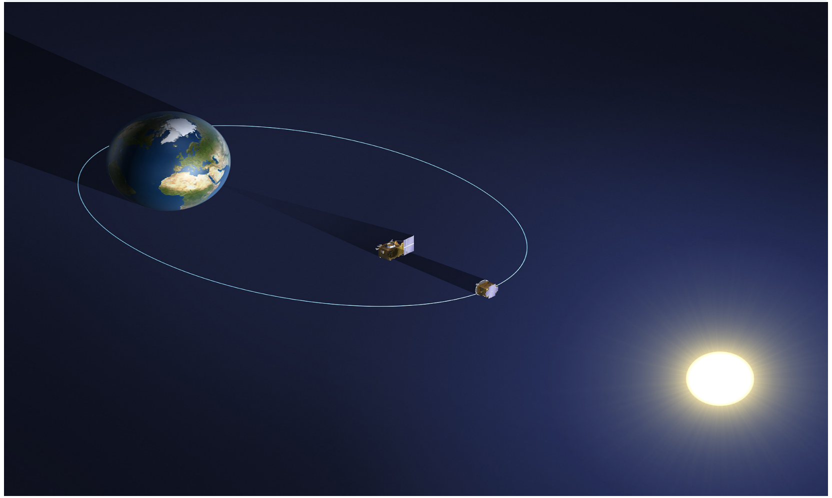




GNSS Signal Availability Analysis – Orbits

Osculating elements	Proba-3 master / chaser
a	36943 km
e	0.8111
i	59 deg
ω	188 deg
Ω	152 deg
ϑ	0 deg / -0.016 deg
$h_{per.}$	601 km
$h_{apo.}$	60529 km
$d_{m\text{-}c\ @\ per.}$	2 km
$d_{m\text{-}c\ @\ apo.}$	0.2 km

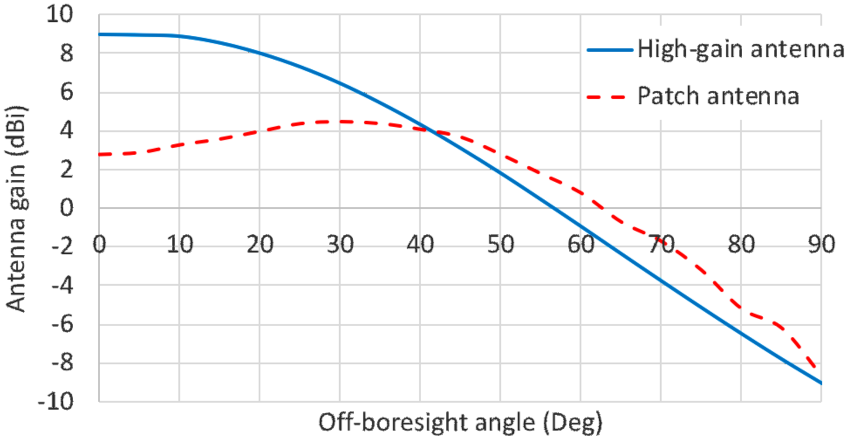
Galileo constellation	GPS constellation
24 satellites	27 satellites
All data regarding the GNSS constellations orbits are taken from the ICG SSV Booklet*	



*_The Interoperable Global Navigation Satellite Systems Space Service Volume_, United Nations, Vienna 2018

GNSS Signal Availability Analysis - Link-Budget

1. **Receivers' antennas**
   a. High-Gain Antenna nadir pointing
   b. Patch antenna zenith pointing
2. **Receivers' CN0 thresholds**
   a. 20 dBHz
   b. 30 dBHz



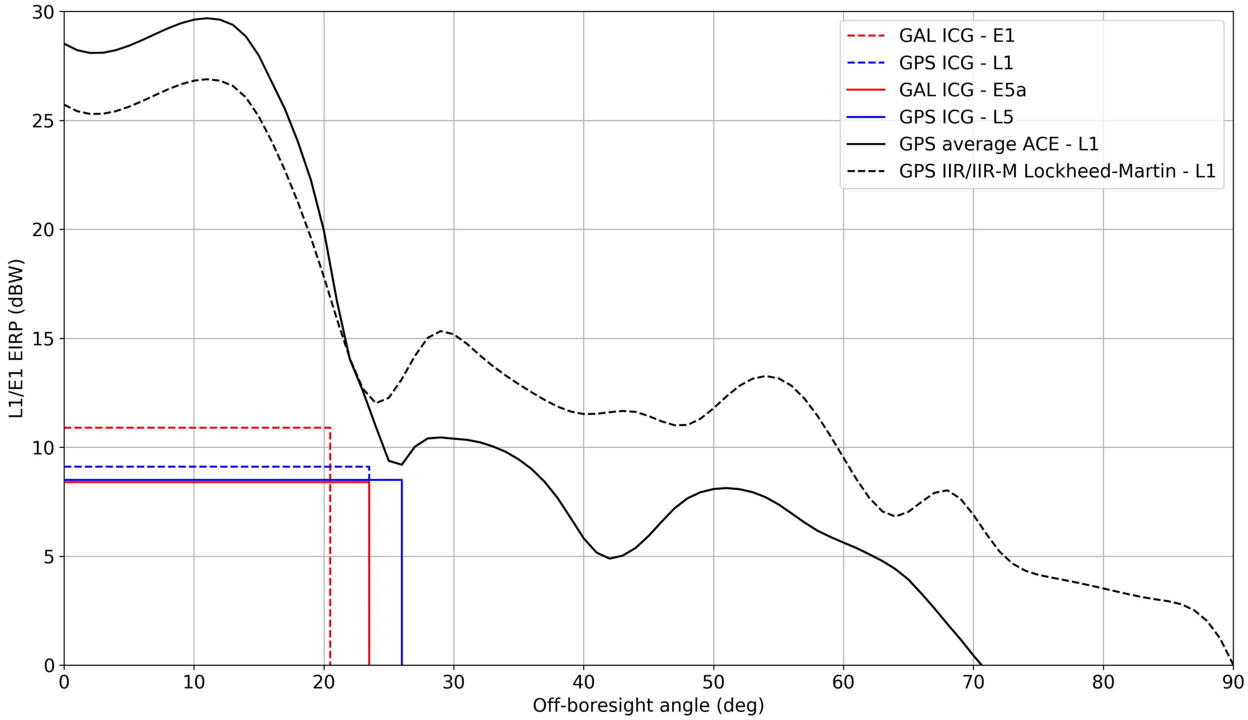
Source: GNSS SSV Booklet

3. **GNSS EIRP**
   a. ICG Galileo E1 & E5a
   b. ICG GPS L1 & L5
   c. NASA ACE estimation from GEO L1
   d. Lockheed Martin sheets L1 (improved)*

USER satellite attitude is nadir-pointing and USER antenna is also pointing in this direction

**GPS Block IIR and IIR-M Antenna Panel Pattern*, Marquis, Feb 2014

EIRP Galileo E1/E5a & GPS L1/L5



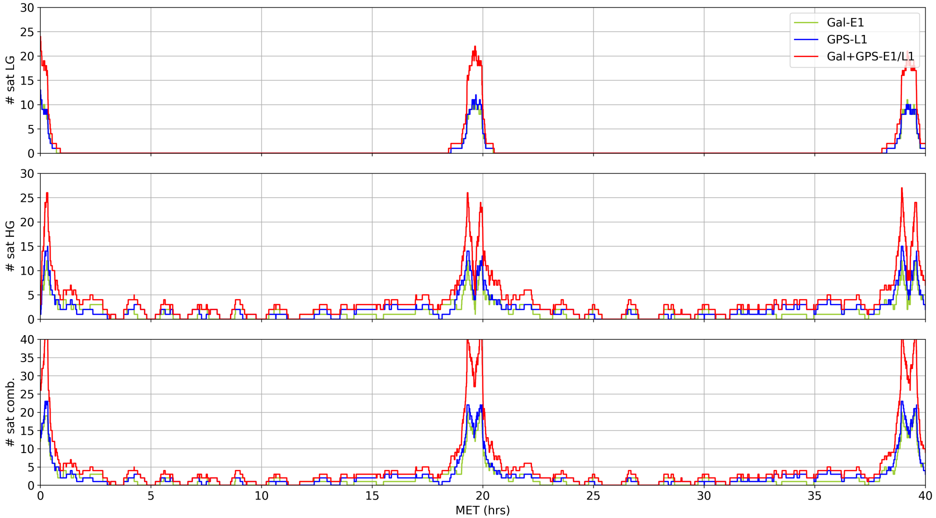
Selected Galileo & GPS EIRP patterns for simulations

GNSS Signal Availability - Scenarios

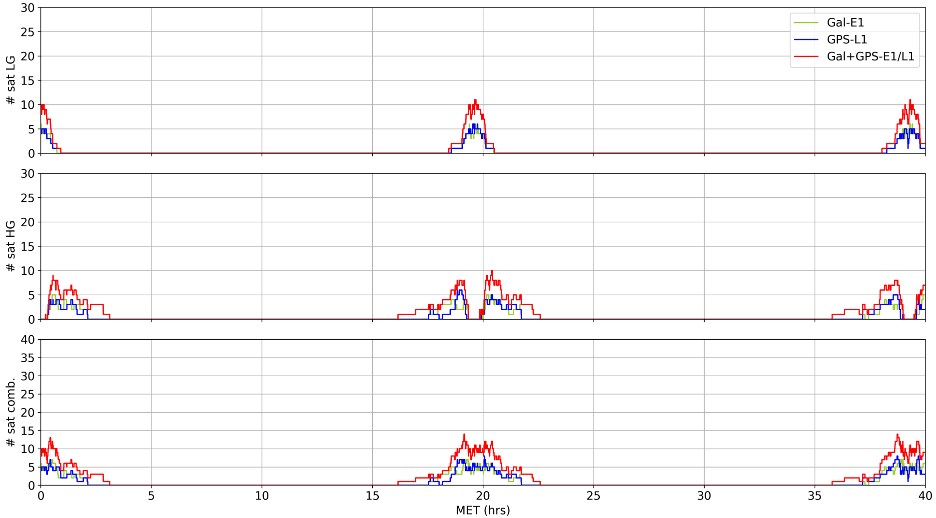
	Galileo EIRP	GPS EIRP
Scenario #1	ICG E1	ICG L1
Scenario #2	ICG E5a	ICG L5
Scenario #3	ICG E1	ACE L1
Scenario #4	ICG E1	Lockheed Martin L1

GNSS Signal Availability - Results

	Galileo EIRP	GPS EIRP
Scenario #1	ICG E1	ICG L1



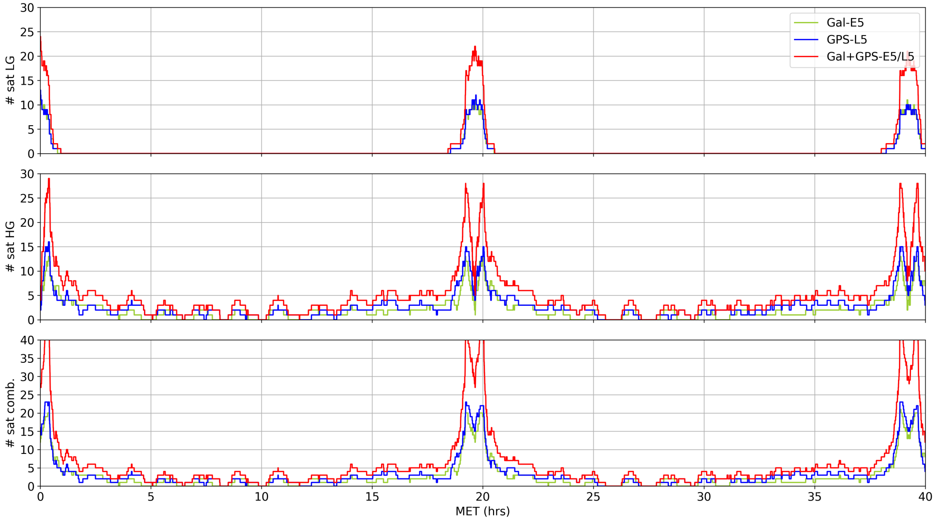
$CN0_{min} = 20dB\text{-}Hz$



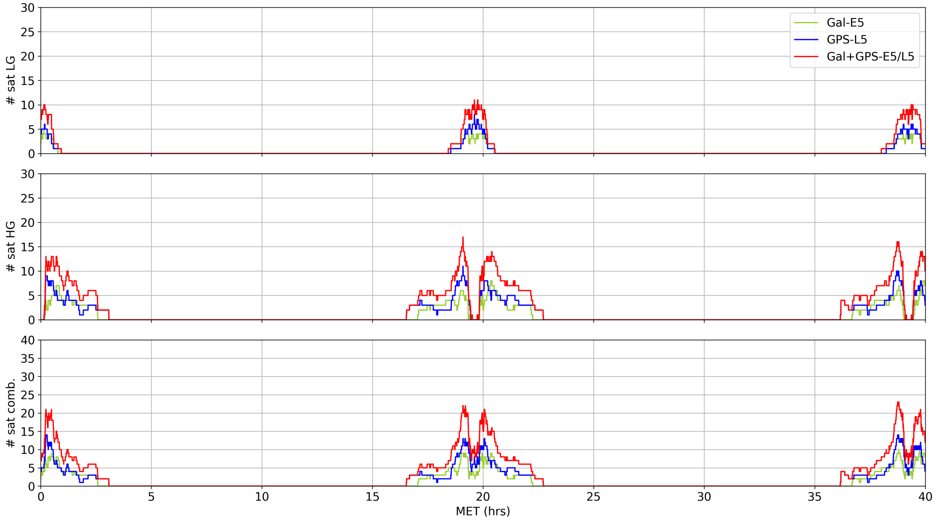
$CN0_{min} = 30dB\text{-}Hz$

GNSS Signal Availability - Results

	Galileo EIRP	GPS EIRP
Scenario #2	ICG E5a	ICG L5



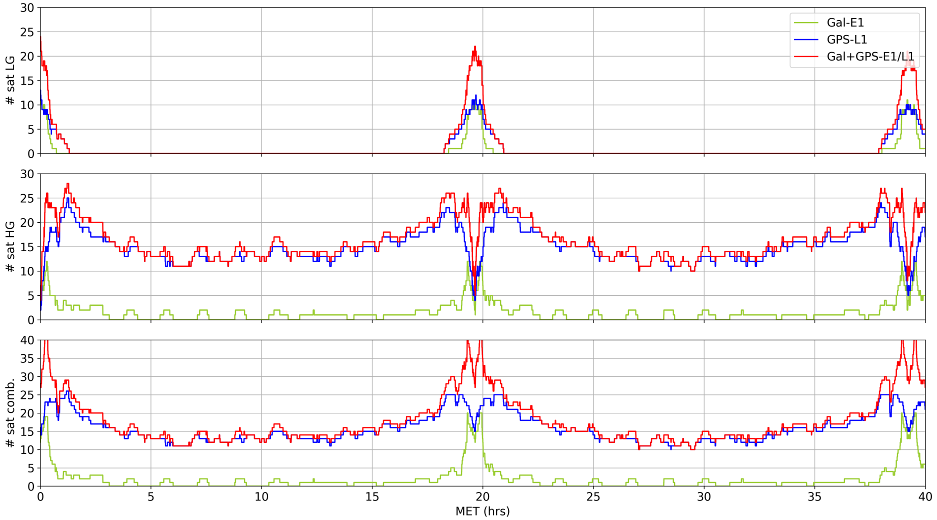
$CN0_{min}$ = 20dB-Hz



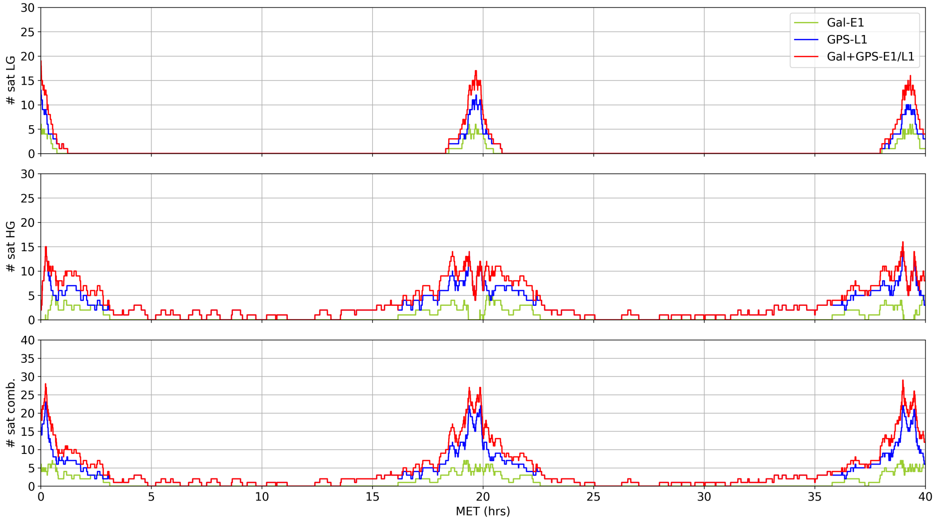
$CN0_{min}$ = 30dB-Hz

GNSS Signal Availability - Results

	Galileo EIRP	GPS EIRP
Scenario #3	ICG E1	ACE L1



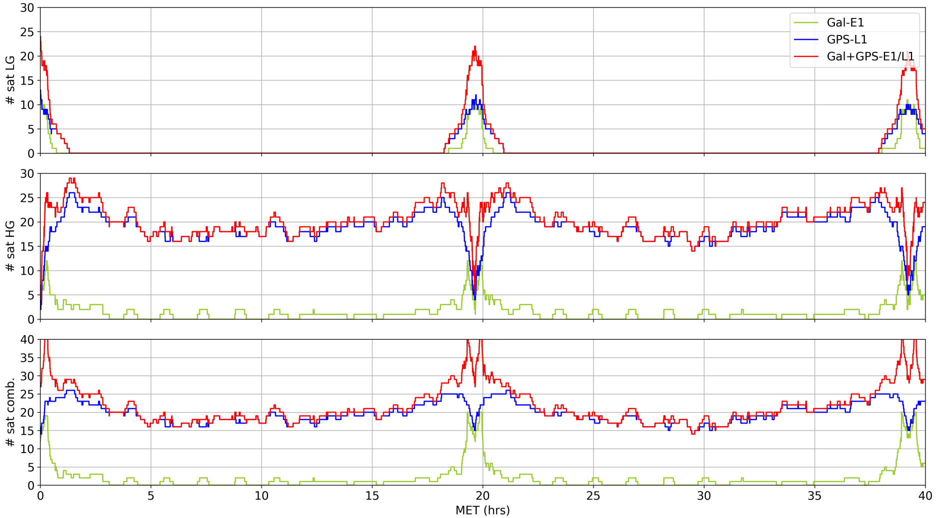
$CN0_{min}$ = 20dB-Hz



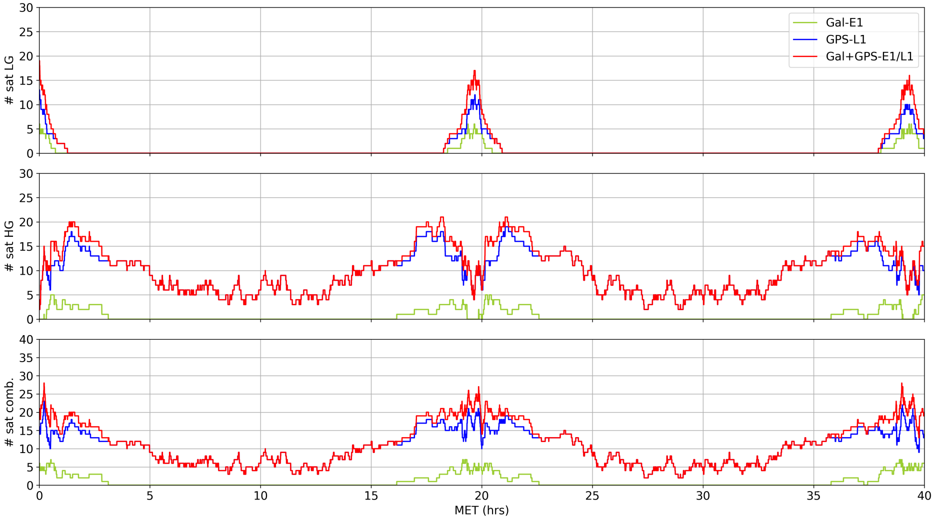
$CN0_{min}$ = 30dB-Hz

GNSS Signal Availability - Results

	Galileo EIRP	GPS EIRP
Scenario #4	ICG E1	Lockheed Martin L1



$CN0_{min} = 20dB\text{-}Hz$



$CN0_{min} = 30dB\text{-}Hz$

GNSS Signal Availability - Results

Number of GPS available signals during the apogee phase

	$CN0_{min}$ = 20 dB-Hz	$CN0_{min}$ = 30 dB-Hz
ICG L1	0 - 2	0
ICG L5	0 - 3	0
ACE L1	10 - 16	0 - 3
L.M. L1	15 - 22	2 - 13

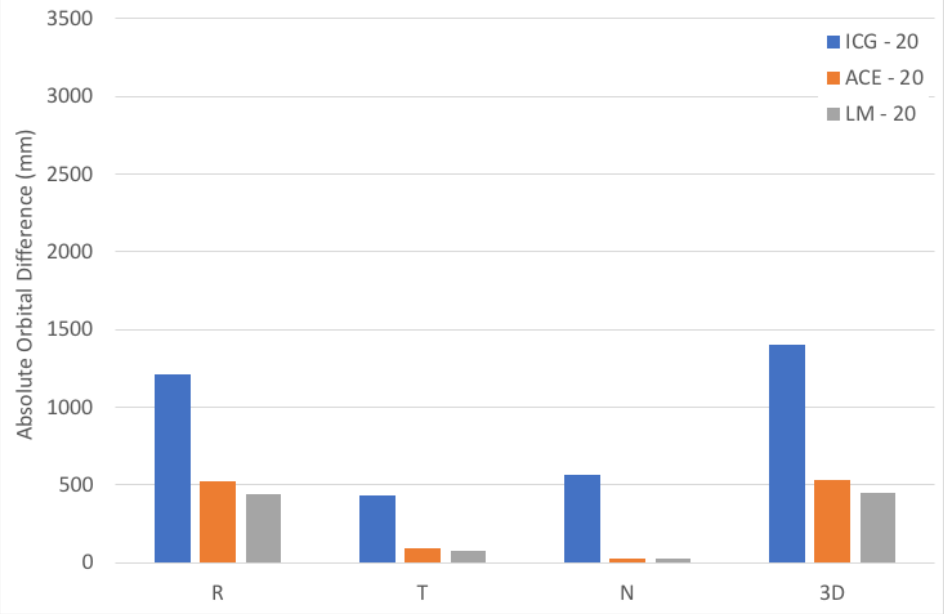
Higher EIRP in secondary lobes → better availability at high altitudes

Precise Orbit Determination - POD

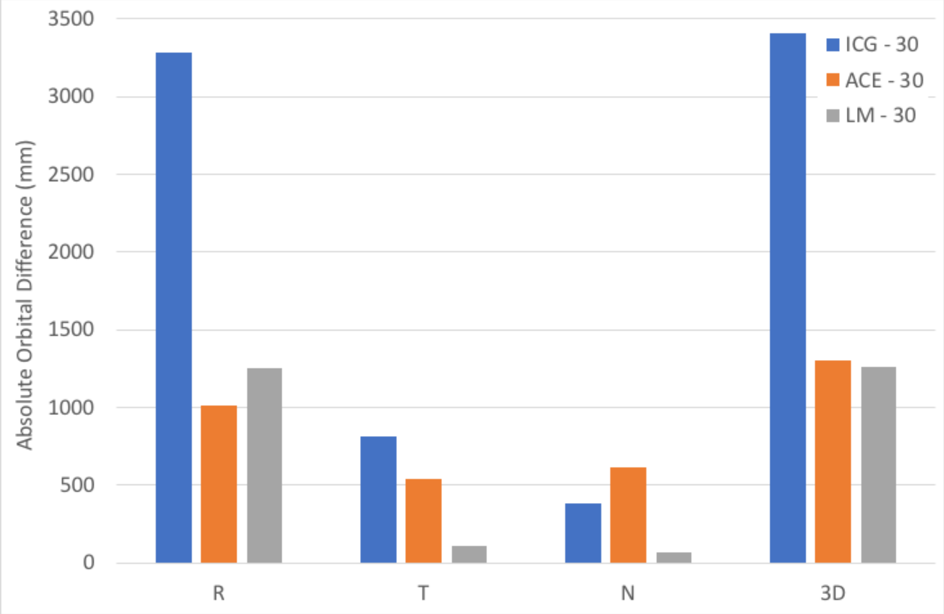
- **POD inputs**
  - Galileo E1 and GPS L1 have been simulated and used, as the E1/L1 signals availability is more conservative than the E5a/L5 one
- **POD processing:**
  - A dynamic Least-Square-Adjustment approach has been adopted
  - Systematic errors have been introduced in the dynamics to make the scenarios more realistic
- **POD options for GNSS Observations to be used in POD processing:**
  1. RAW approach: all available signals, no linear combinations, no differences
  2. Dual-frequency linear combination (e.g., iono-free)
  3. Single frequency linear combination (e.g., GRAPHIC) → selected (conservative) approach

Preliminary POD results: Absolute orbital error

CN0 = 20 dBHz



CN0 = 30 dBHz



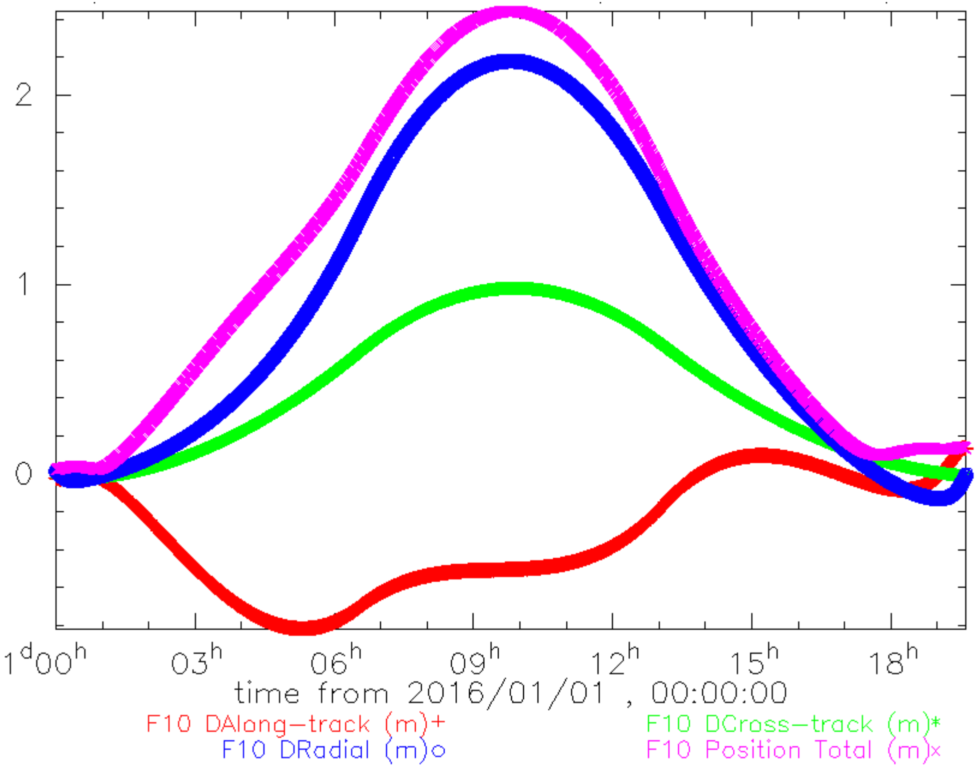
Estimated orbit VS reference orbit (R, T, N and 3D RMS)

More observations → better POD performances

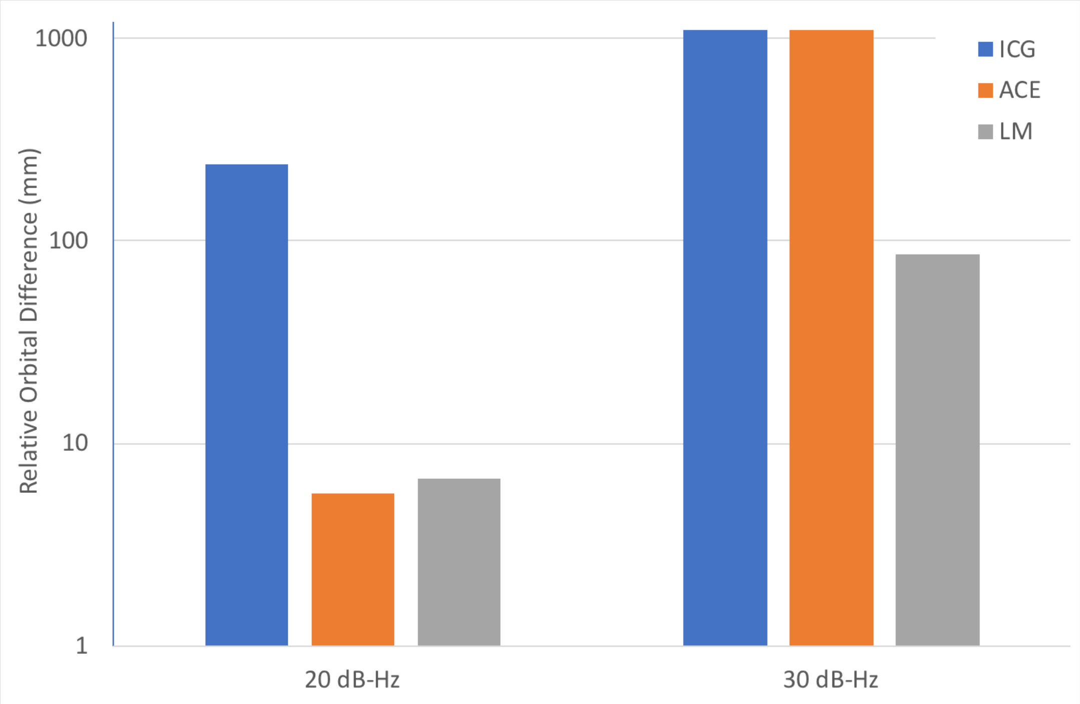
Processing results: Absolute orbital error

Example of
epoch-wise orbit
comparison for the
scenario #1
Gal E1 ICG+ GPS L1 ICG

Orbital difference is higher at the apogee



Preliminary POD results: Relative orbital error



Estimated baseline VS reference baseline (3D RMS)

More observations → better POD performances

Conclusions 1/2

GNSS Signal Availability Analysis

- Conducted GNSS signal availability analysis for PROBA-3 confirms that the results from ICG are quite conservative, because only the main lobe is considered
- The GPS L1 ACE estimated antenna pattern (main lobe + side lobe) is considered as being consistent with the data sheets from Lockheed Martin and provides a significant improved GNSS signal availability for PROBA-3 compared to ICG
- A receiver capable of acquiring and tracking a signal level of 20 dB-Hz CN0 will have GNSS signal visibility of more than 4 GNSS satellites for the entire PROBA-3 orbit

Conclusions 2/2

Precise Orbit Determination – POD Accuracy Aspects

- The GNSS observations selected for the initial POD are considered as sub-optimal from an accuracy point of view, but very well suited to show the impact of GNSS signal availability to the POD accuracy
- The initial POD results demonstrate already the orbital accuracy improvement that derives from the higher number of GNSS signals available, in terms of absolute and also relative orbit accuracy for the PROBA-3 mission
- POD based on the RAW approach is considered as optimal and will assure the availability of all the GNSS observations to the process and therefore improved orbit accuracy (absolute and relative)

Lessons learn and way forward

- The dynamical parameterization commonly adopted for POD might not be adapt to the orbital elliptical shape (e.g., CPRs)
- As the orbital period is almost 20 hours and the orbit is highly eccentric the numerical integration has to be carefully tested and evaluated
- The simulated scenarios will be improved to better understand the POD-related issues and achievable accuracy (especially at high altitudes) and to prepare for the actual Proba-3 mission processing campaign

Contact persons at ESOC

- Werner Enderle: Werner.Enderle@esa.int
- Francesco Gini: Francesco.Gini@esa.int
- Erik Schönemann: Erik.Schoenemann@esa.int

Thank you for your attention