The joint ESA/NASA Galileo/GPS Receiver on-board the ISS – The GARISS Project

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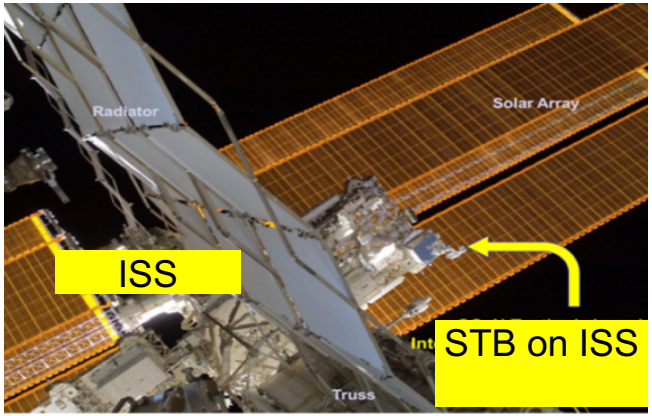
Project Background

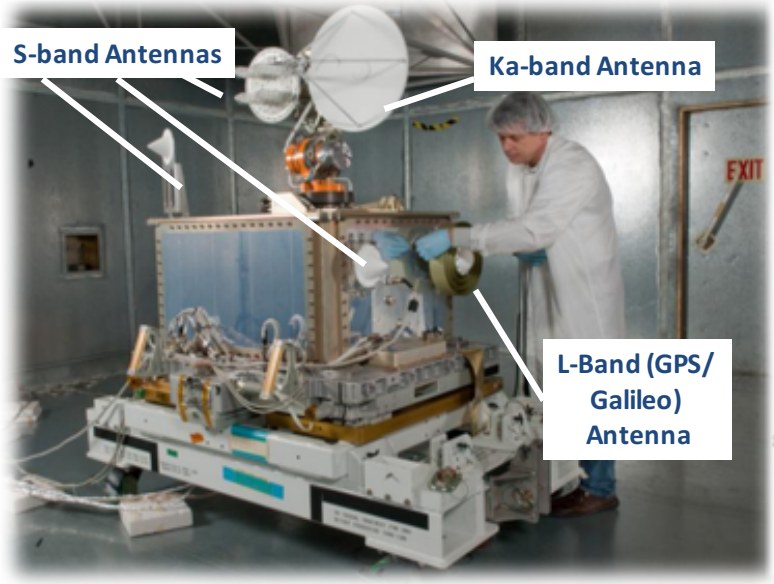
- Initial discussions between ESA and NASA at international meetings, starting mid 2014
- Cooperation agreement for this joint project signed in 2016
- Waveform design and development in 2016/2017
- Test and validation of Galileo/GPS waveform in 2017
- Operations of experiment: start in 2018 ending in May 2019

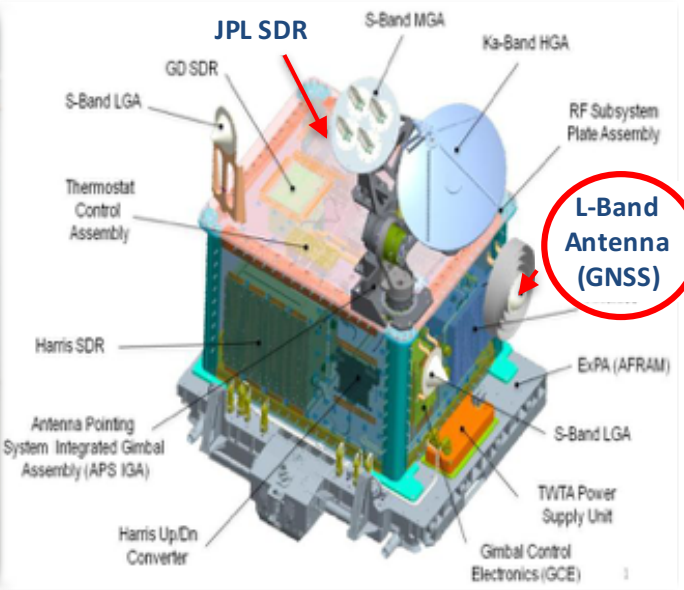
Project Objectives

- Demonstrate operations of combined GPS/Galileo navigation receiver on-orbit with upload of Software Radio waveform to NASA's Space Communication and Navigation (SCaN) Testbed on-board ISS
- Analysis of Galileo/GPS signal performance
- Analysis of PVT performance with different algorithms
- Processing of GNSS raw data and perform Precise Orbit Determination of ISS
- Demonstrate the benefits of combined Galileo/GPS receiver



Infrastructure on-board ISS – NASA's SCaN Testbed



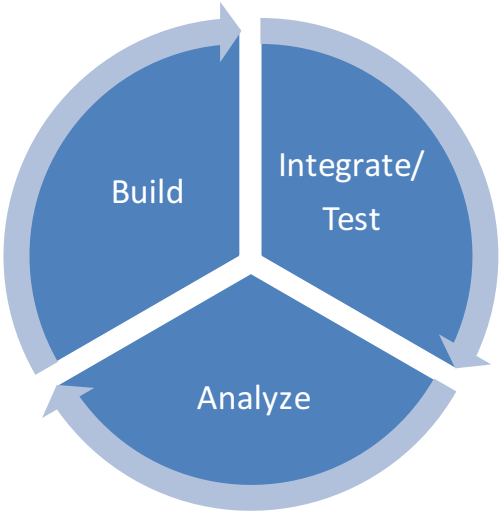


Installed on the International Space Station (ISS) in July 2012

Fully reprogrammable Software Defined Radio capability at L-band

Development Process

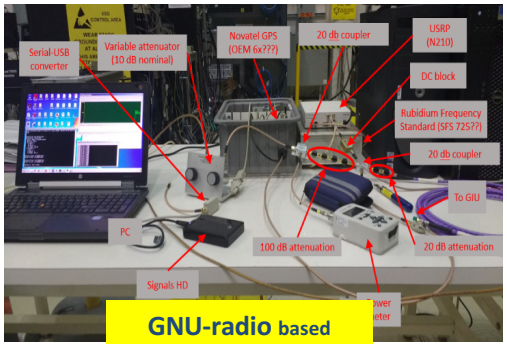
- Base NASA JPL platform contributions:
  - GPS Module, bus logic, STRS Operating Environment (OE)
- ESA contract to Qascom for
  - Core waveform design contributions
  - Core SW development/Core FW development
  - SW Test/Validation
- NASA GRC technical contributions
  - Interrupt Service Routine (ISR) development
  - Waveform integration
  - System Test/Validation

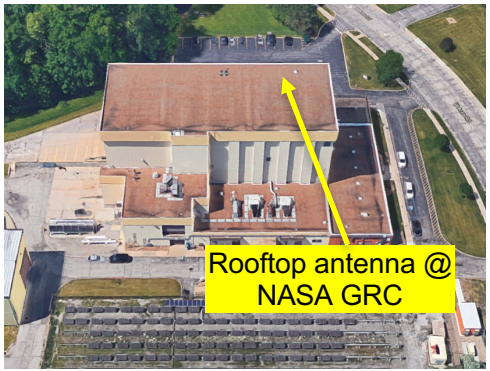


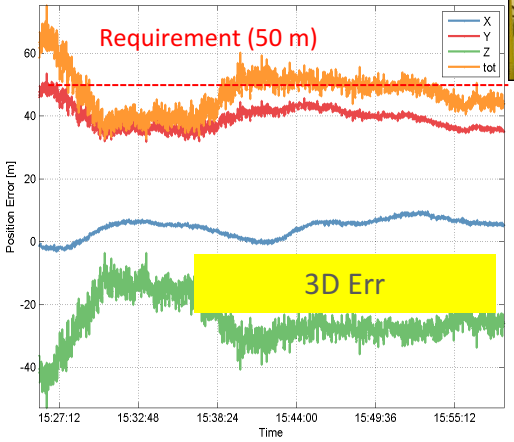
NASA/ESA effort brings together products and efforts from multiple labs and contractors including Qascom S.r.l. NASA GRC, JPL, and JSC

Development and Testing

- Allocated functions to serial and Field Programmable Gate Array (FPGA) processor, co-processing architecture
- Integrated Qascom modules into STRS waveform
- Extensive debugging with recorded data
- Successful acquisition, track and PVT with STB Ground Integration Unit (GIU) using roof antenna (March 2018)

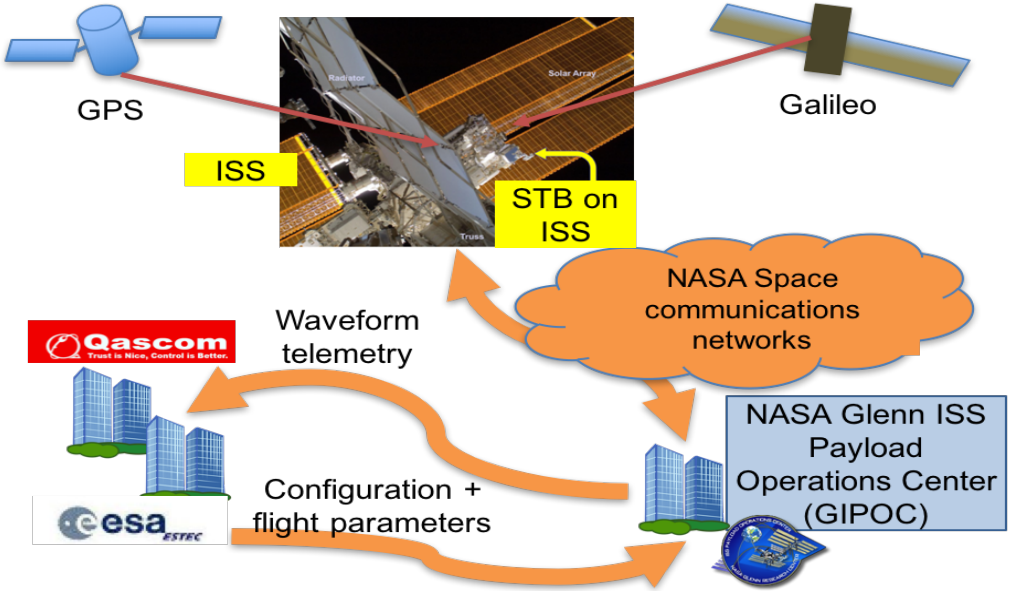






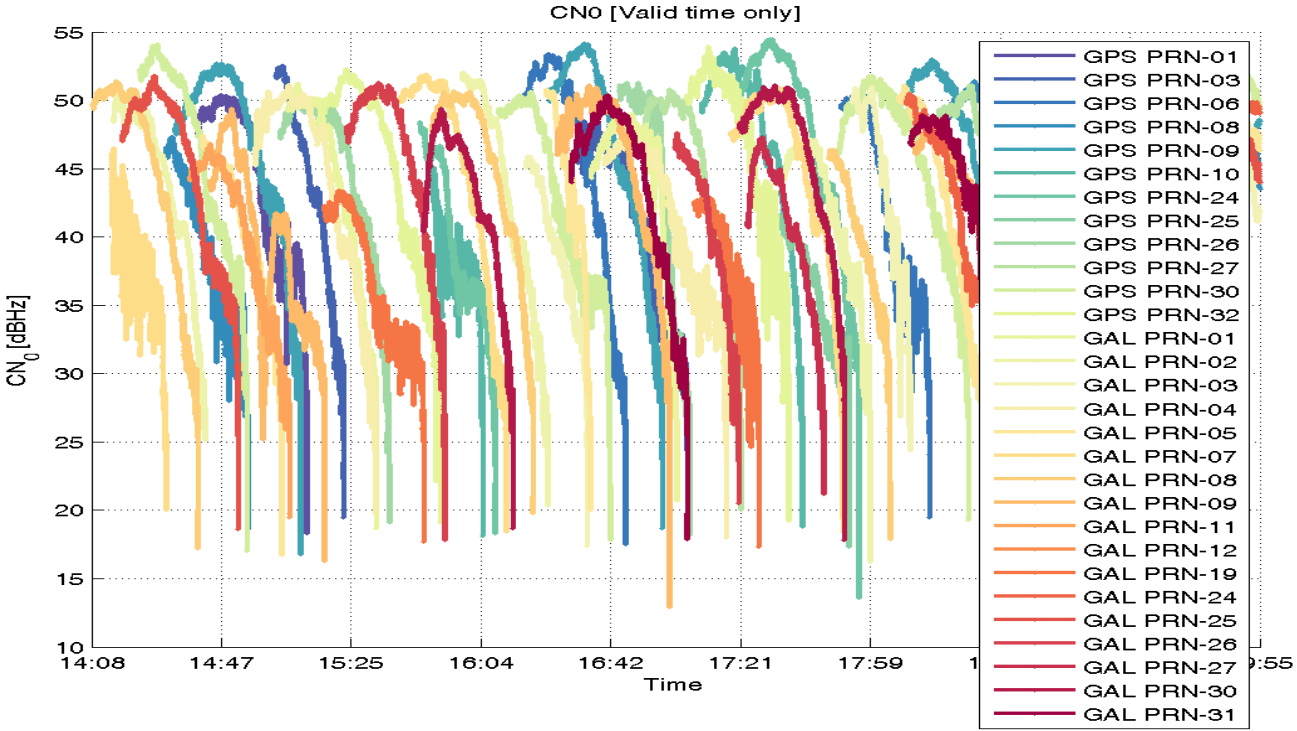
Operations Concept

- Transfer waveform from ground support equipment to STB
- Operate waveform per ISS and STB operations schedule
- Collect/process log data
- Warm start acquisition aiding from ground via file upload (GGTO, SV, ISS ephemeris)
- Assess acquisition and tracking performance, pseudo-range errors, PVT performance, etc.

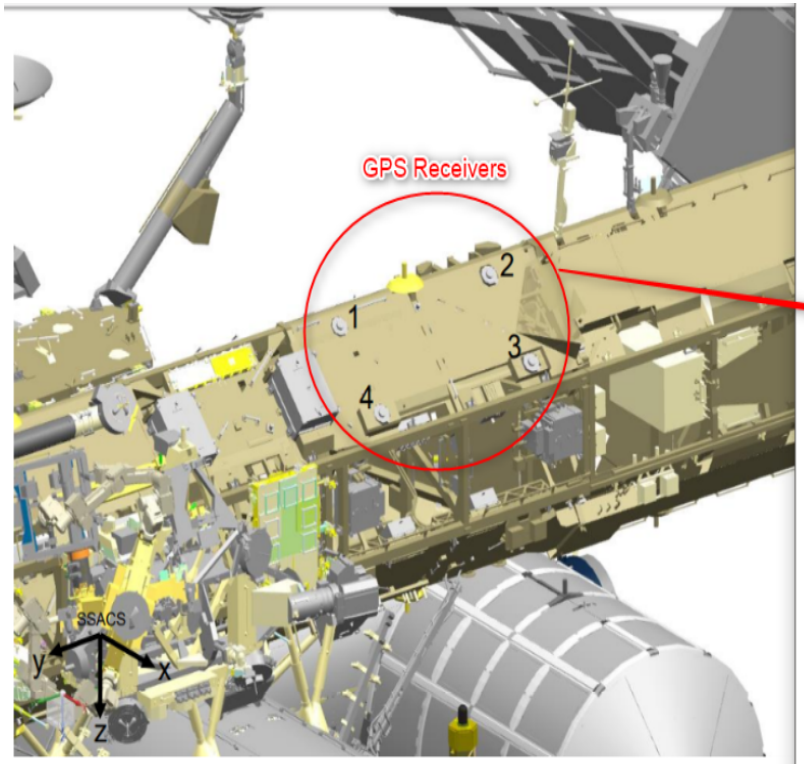


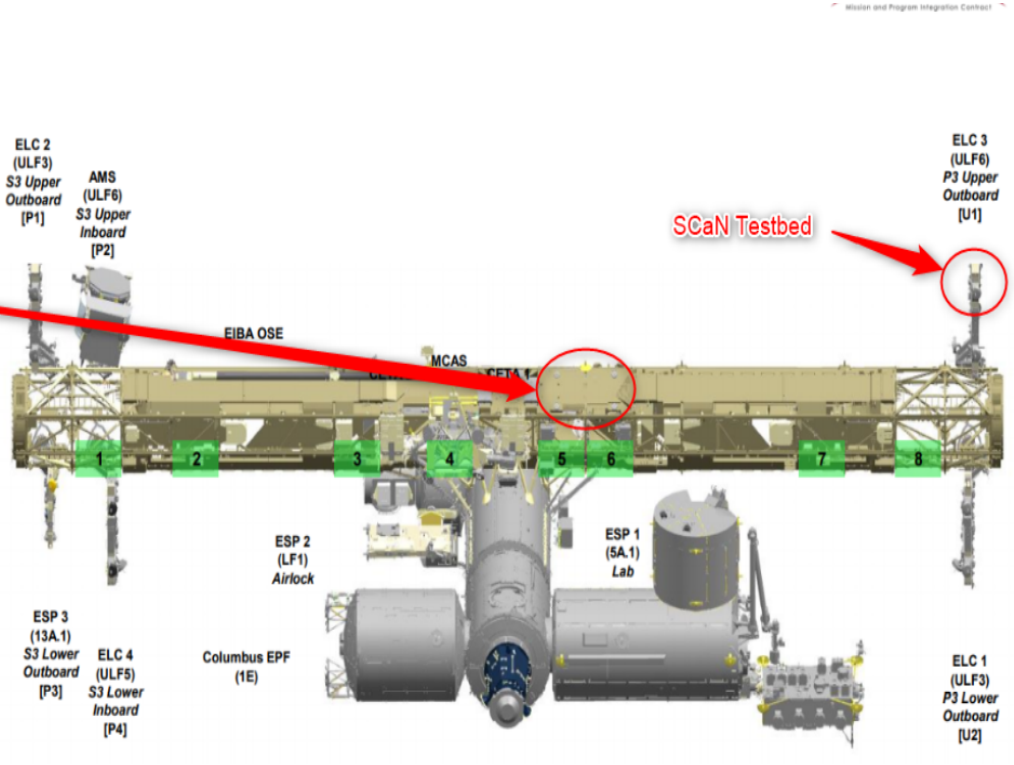
Results – Signals

2018-08-28: Tracking Data (GPS L5 + GAL E5a)

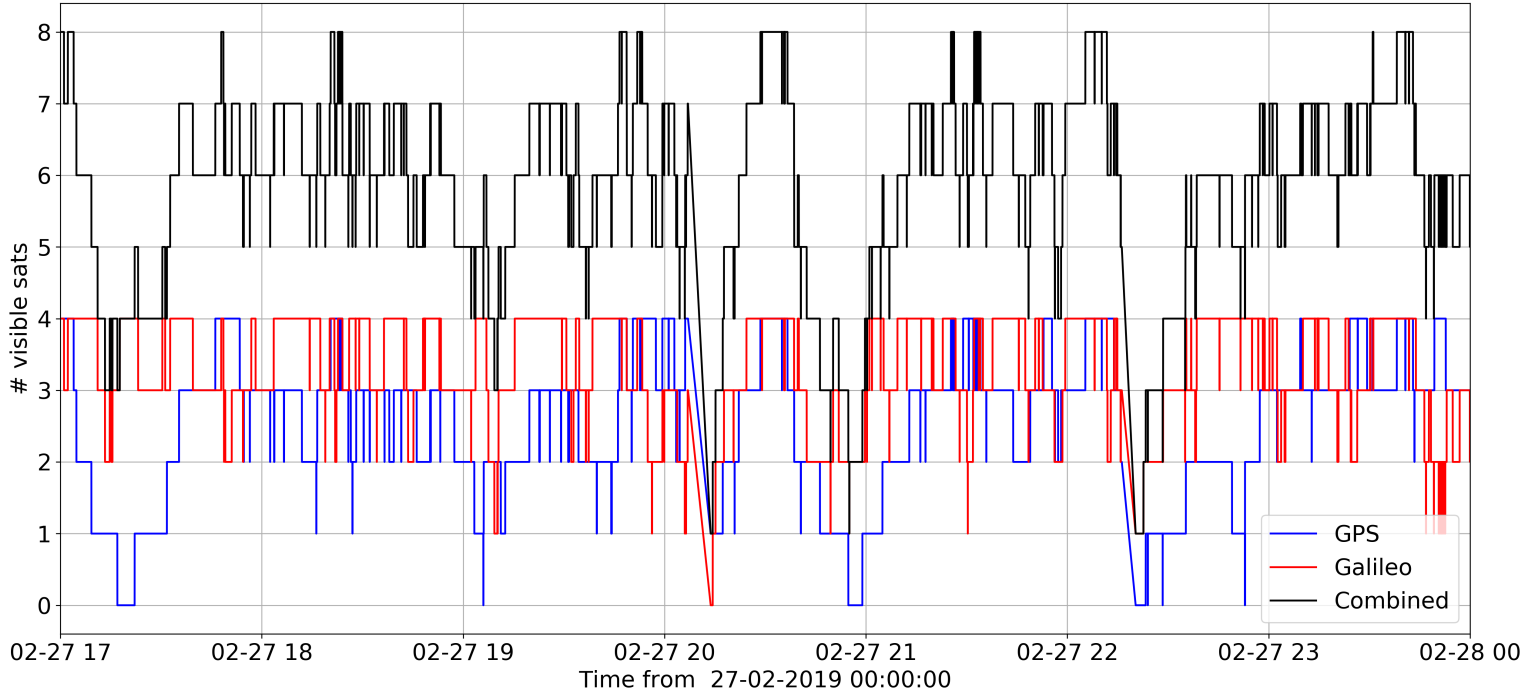


Results – Reference System Offset



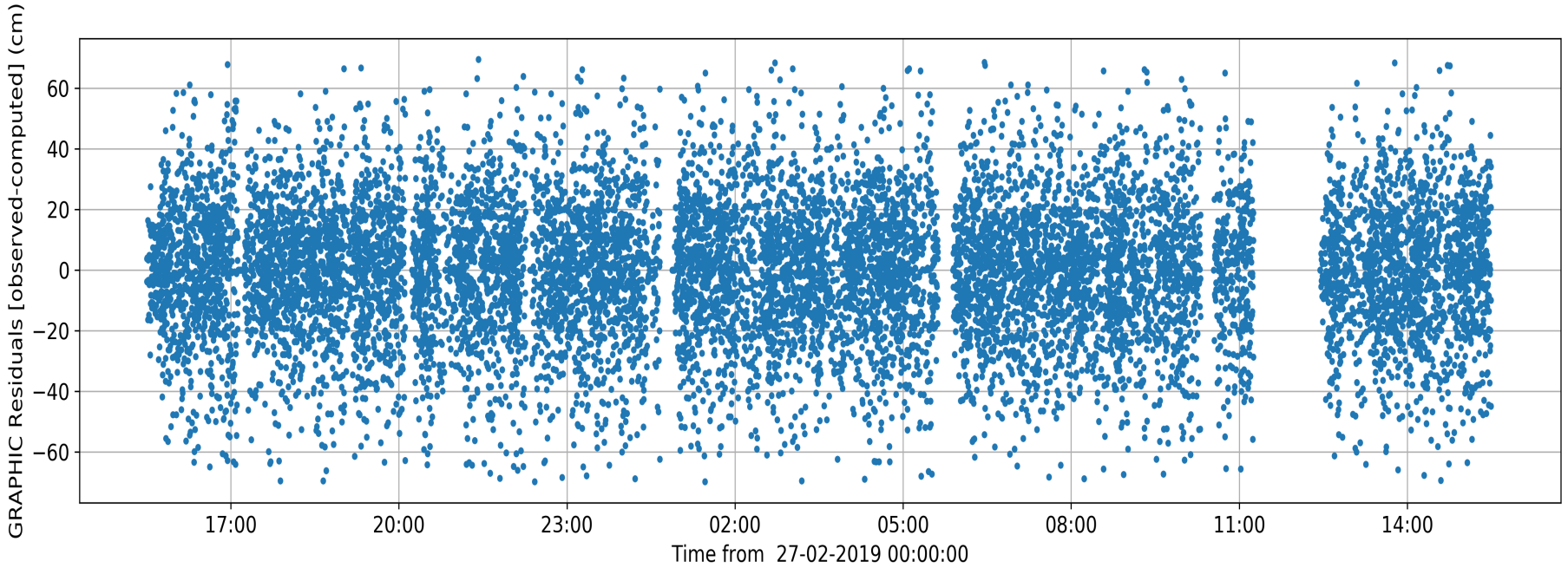


Analysis and Results – Added Value of Interoperability for Galileo and GPS

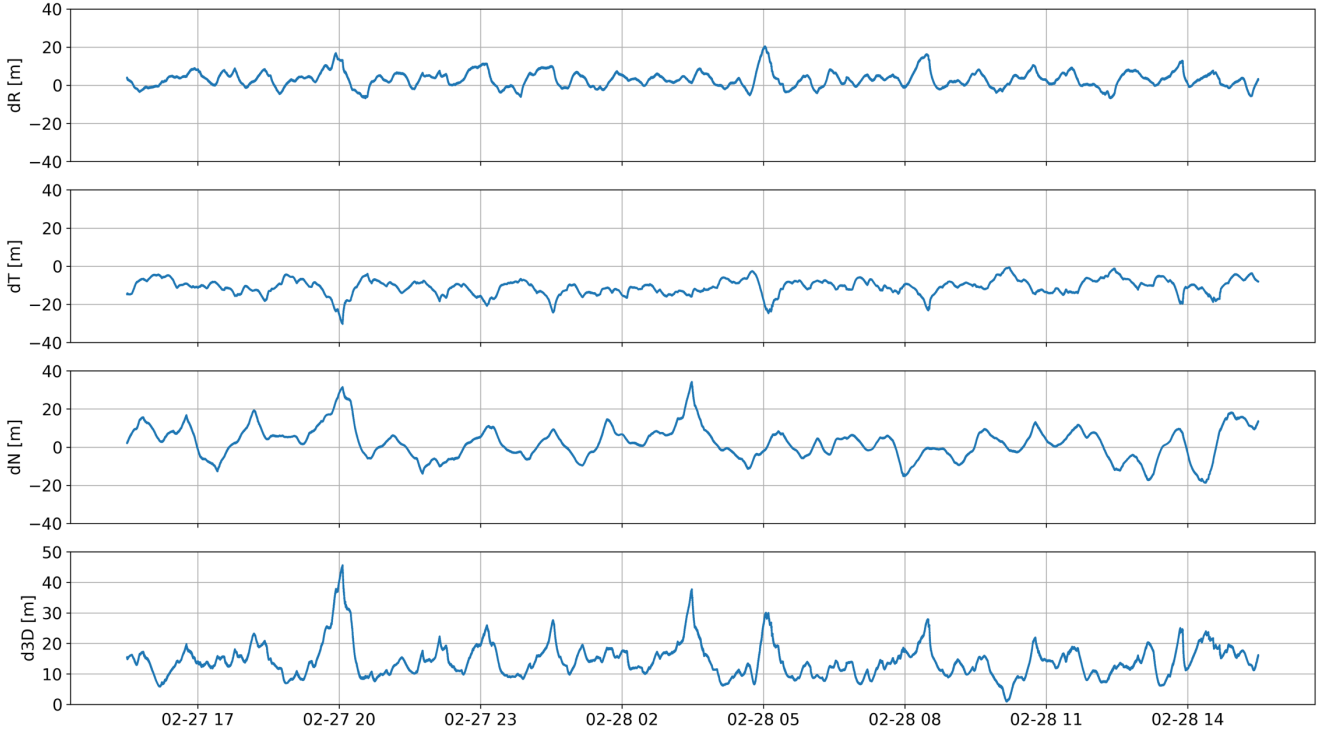


Analysis and Results – (Precise) Orbit Determination 1/2

GRAPHICs Residuals (RMS) ~20 cm



Analysis and Results – (Precise) Orbit Determination 2/2



ESA POD solution vs NASA real time PVT on-board solution From a Single Freq Receiver

RMS (m)	
Radial	3.1
Along -track	-10.9
Cross- track	2.3
3D	15.5

Conclusions 1/2

- Excellent cooperation between the ESA/Qascom and NASA teams
- Combined Galileo/GPS waveform was uploaded to NASA's SCaN Testbed on-board the ISS and also operated
- **First PVT in space based on Galileo/GPS E5a/L5 signals**
- Galileo/GPS performance was analyzed and improved during experimental phase
- The added value of an interoperable Galileo/GPS receiver for space users could be clearly demonstrated

Conclusions 2/2

- Only Orbit Determination could be conducted, but not Precise Orbit Determination, because of missing dual frequency observations
- Raw observations (E5A/L5) from GARISS have a demonstrated good quality (consistent code and phase observations)
- ESOC orbit solution comparison to ISS on-board PVT solution has a 3D RMS of around 15 m
- Orbit comparison accuracy does not match the very good residuals for the GRAPHIC observations (20cm) -> further investigations are needed

Overall Conclusion

Very successful experiment and cooperation

Acknowledgement – Excellent Cooperation between ESA/NASA and European Industry

ESA/European Industry	NASA
Werner Enderle	Jim Miller
Erik Schoenemann	Obed (Scott) Sands
Francesco Gini	David Chelmins
Michiel Otten	Bryan Welch
Pietro Giordano	Nick Tollis
Massimo Crisci	Larry Young
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