Status of the Gravitational Redshift Test with Eccentric Galileo Satellites

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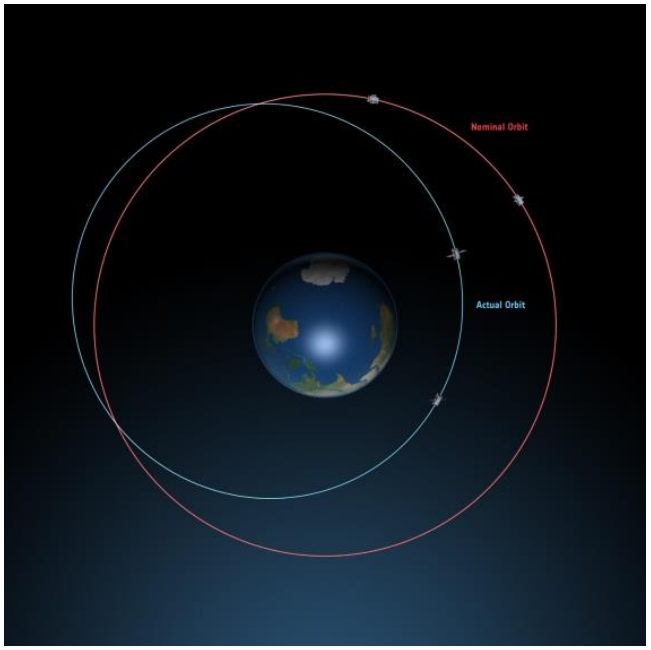
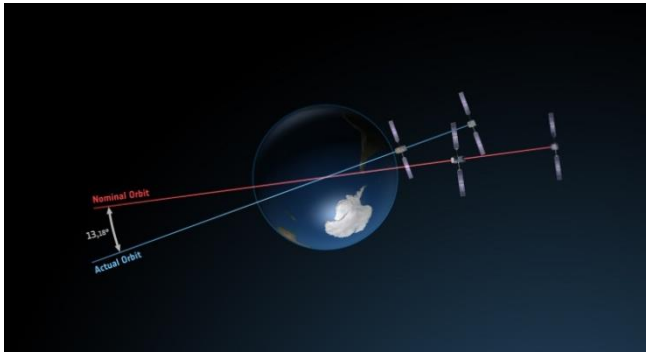
Contents

GALILEO Launch M-3

Galileo 5 & 6 (GSAT0201/0202):

- First pair of Satellites of the FOC family
- Launched 22/08/2014 by Soyuz VS09 from Kourou Spaceport
- High eccentric Injection Orbit due to anomaly in the upper stage of the Launch Vehicle





GALILEO

SAT 5-6

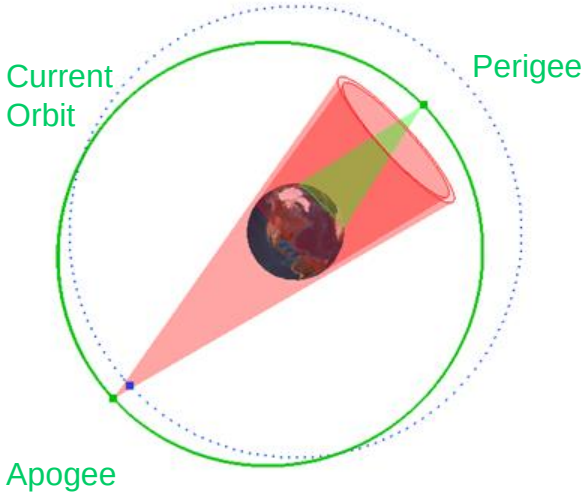
GSAT0201/0202 Orbit Recovery

Both spacecraft safely raised to final orbit:

- Perigee raised from **13700** to **17200** km
- Eccentricity reduced from **0.23** to **0.15**

Broadcast of Dummy Messages on all Signals initiated in 2015 to support GREAT scientific experimentation

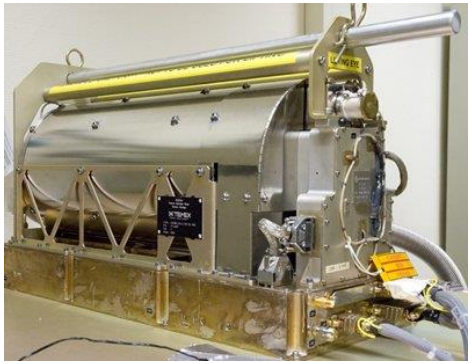
Navigation Message broadcast on all Signals started on August 5th, 2016 on both satellites for test purposes



GALILEO features supporting GREAT

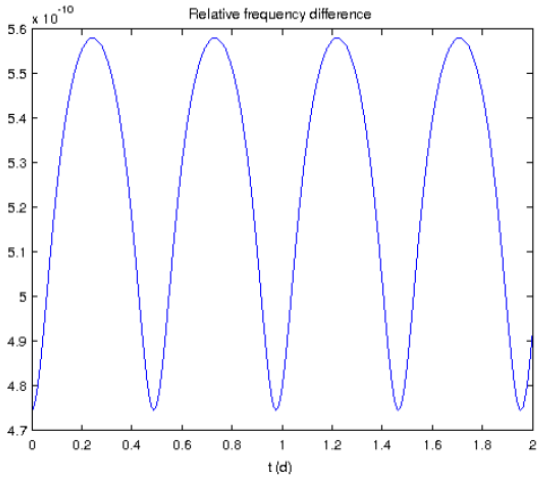
GSAT 0201/0202 injection anomaly provides interesting features for Test on General Relativity especially on the gravitational redshift:

- High eccentricity of the final orbits of 2 satellites of approx. 0.156
- Highly stable on-board time reference through Passive Hydrogen Maser (PHM) space clocks
- Design lifetime allows for long-term observations
- Equipped with laser retro-reflector to support satellite laser ranging
- Satellites permanently monitored by a global ground segment



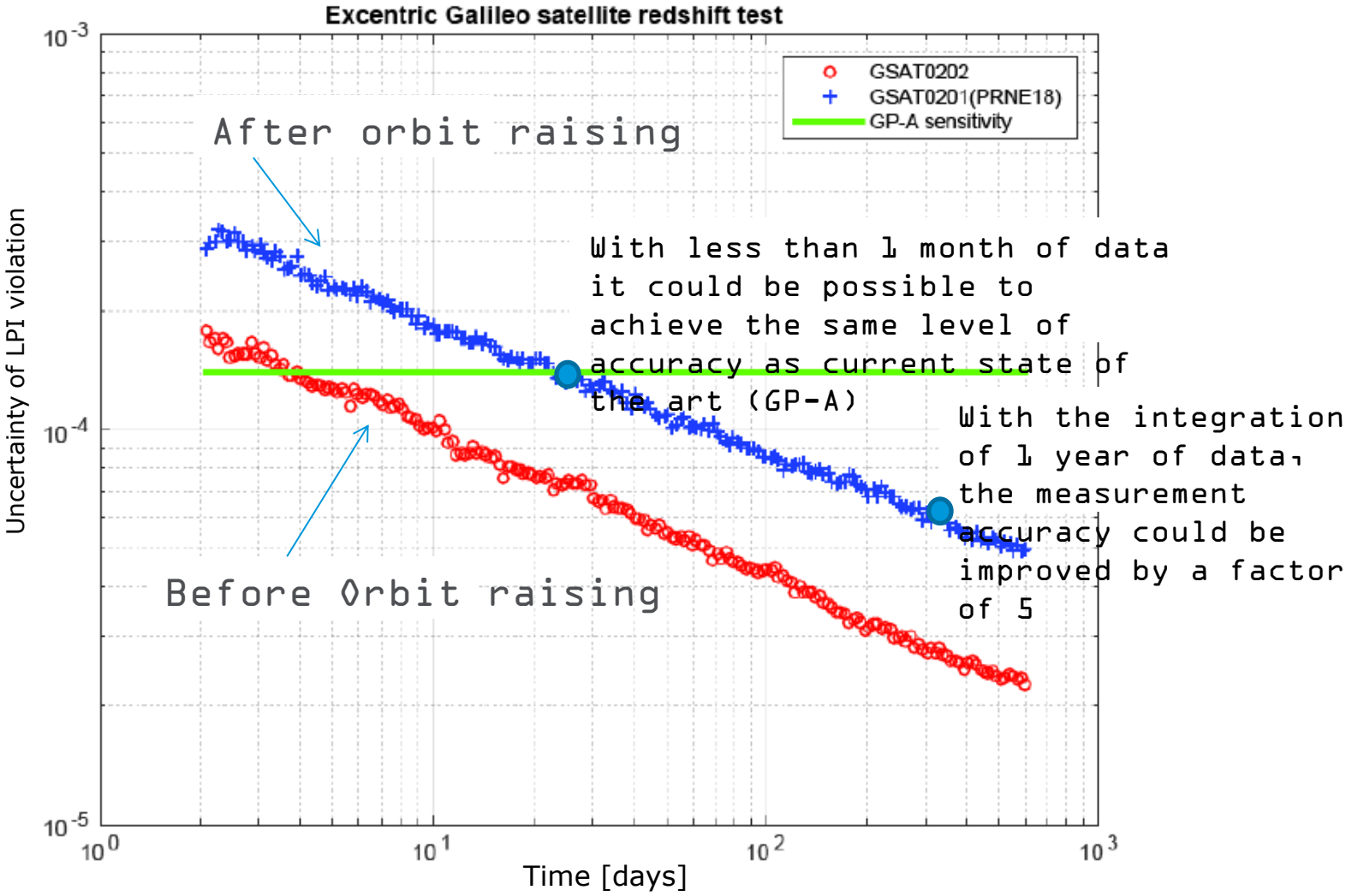
GREAT Test Concept

GREAT: Galileo gravitational Redshift test with Eccentric sATellites



- Orbit eccentricity induces a periodic modulation of the gravitational redshift at orbital frequency
- High stability of the clocks allows to monitor this effect by observing the periodic change of clock rate.
- Change of clock rate is related to the periodic variation of the gravitational potential.
- Averaging these measurement over many orbits (≥1 year) will increase measurement accuracy and allow to push the current state of art by with about 1 order of magnitude.
- Gravity Probe-A - gravitational redshift verified with an accuracy of 1.4 $x10^{-4}$ in 1976

Achievable Accuracy



General Relativity Studies Launched

Galileo Satellites 5 and Sat 6 are perfect candidates to test Gravitational Redshift:

1. The elliptic orbits produce a regular modulation of the gravitational redshift.
2. On-board PHM clocks offer unique clock stability
3. Long satellite life-time with possibility to integrate measurements during a long time
4. Satellites are permanently monitored and include Laser tracking (SLR) possibilities
5. No interference on potential nominal use of Satellites 5 and 6 for Navigation
6. Potentially, the achievable accuracy of the gravitational redshift measurements could become "state of the art" (today best measurements are still based on GP-A experiment performed in 1976)

Two parallel contracts have been launched (Oct 2015) by ESA with SYRTE/Observatoire de Paris and ZARM/University of Bremen to perform these tests in detail.

ZARM

l'Observatoire de Paris | SYRTE

Systèmes de Référence Temps-Espace

Current Status of Study Contracts

The two parallel GREAT contracts are progressing well. By Oct 2016, we have being able to processed about 1 year of data (taking into account the data available in PHM-mode on the 2 available satellites) with encouraging results.

Effort is now focused on the removal of remaining systematic errors via the following activities:

1. Further improve the high accuracy orbit data by ESA/ESOC using better models
2. Further improvement on the Solar Radiation Pressure (SRP) modelling
3. Dedicated Laser ranging campaign launched with ILRS community to disentangle clock and orbit radial errors (campaign on-going http://ilrs.gsfc.nasa.gov/missions/GREAT_exp.html)
4. Acquiring more data from the 2 Galileo eccentric satellites (sat 5 and Sat 6)so to further improve the statistics (the 2 satellites are currently operational)

The tests are encouraging and we expect to have some first consolidated results of these tests by mid 2017. ICG will be duly reported.

Further scientific proposals to exploit GSAT0201/0202 for Fundamental Physics testing are under assessment.