Testing the gravitational redshift effect with Galileo satellites

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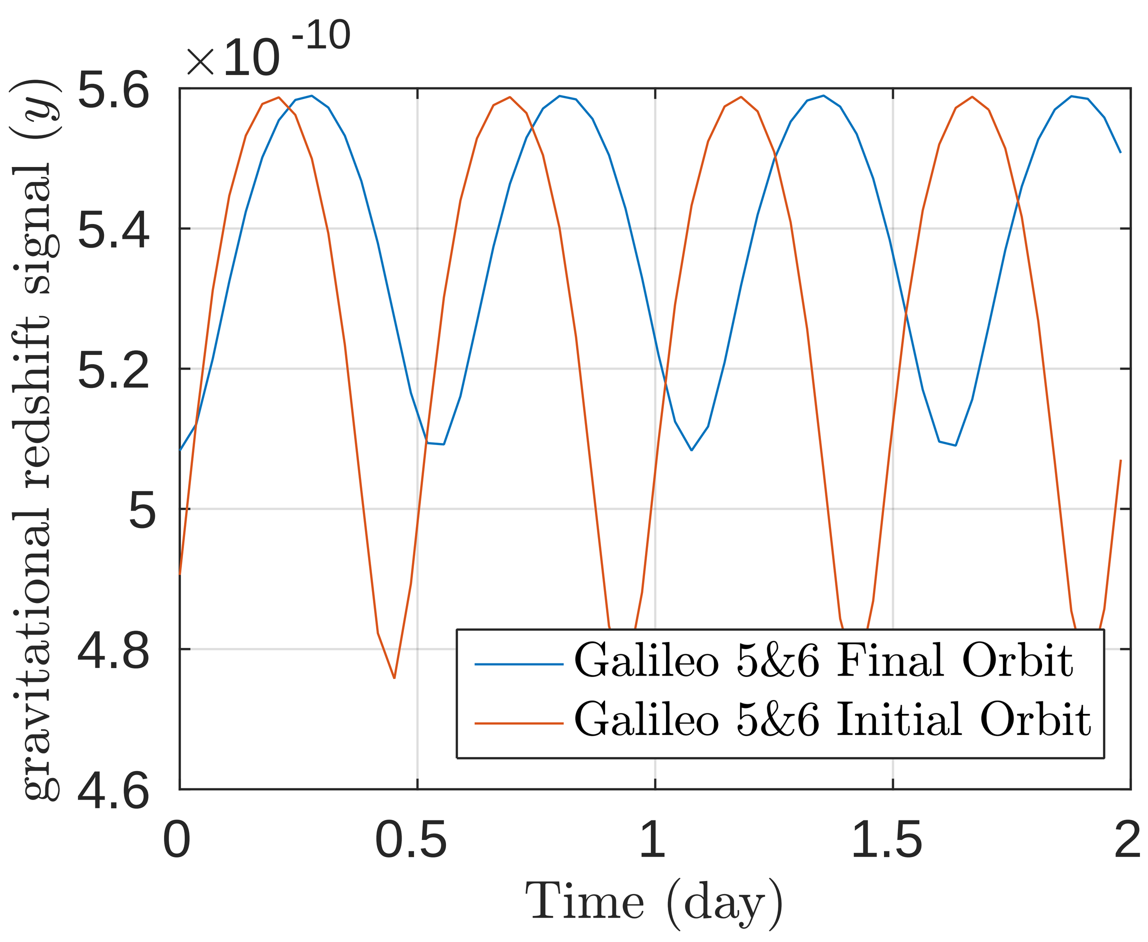
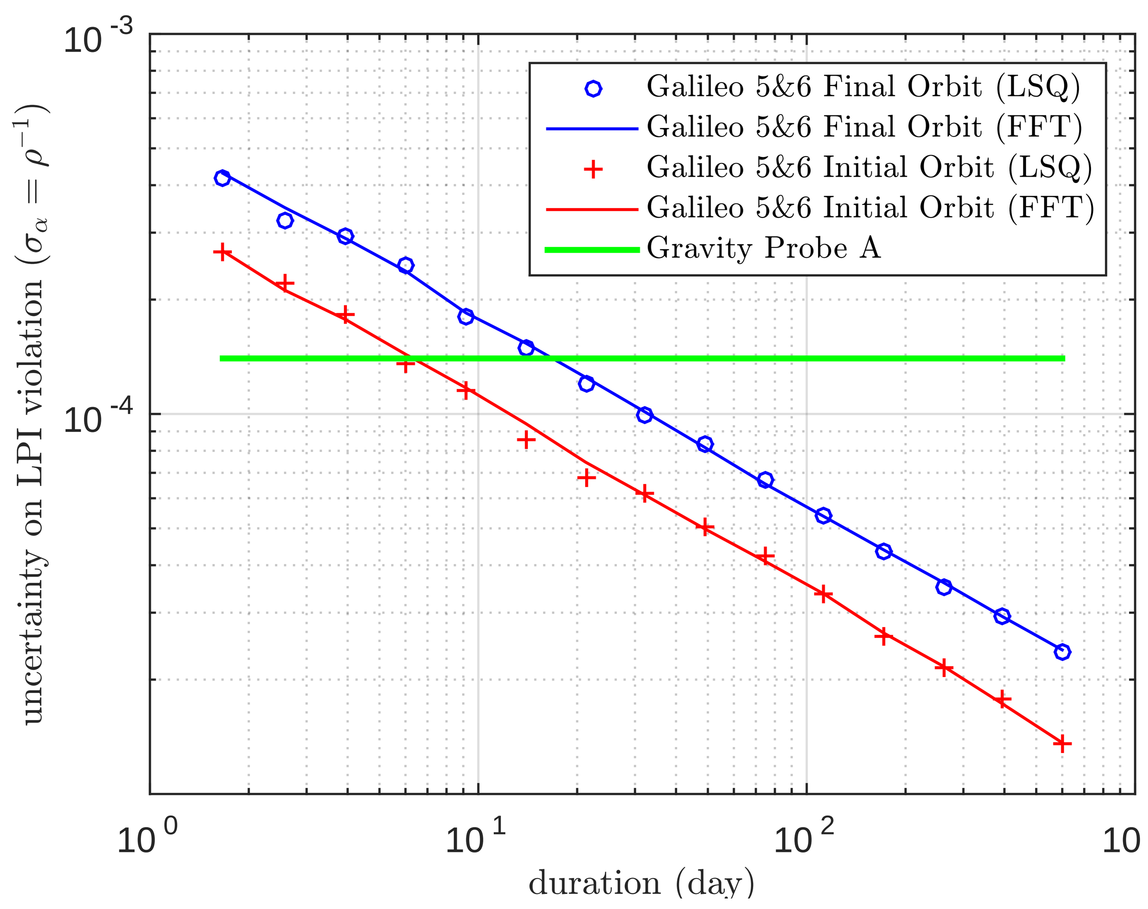
Abstract

The **Einstein Equivalence Principle (EEP)** is one of the foundations of the theory of General Relativity and several alternative theories of gravitation predict violations of the EEP. The EEP can be split in three sub-principles: the **Universality of Free Fall (UFF)**, the **Local Lorentz Invariance (LLI)** and the **Local Position Invariance (LPI)**. We propose to use stable clocks in eccentric orbits to perform a test of the gravitational redshift, a consequence of the LPI. The best test to date was performed with the **Gravity Probe A (GP-A)** experiment in 1976 with an uncertainty of 1.4×10^{-4} [2]. Considering systematic errors, Galileo 5 and Galileo 6 can improve on the GP-A limit of the gravitational redshift test, down to an accuracy $(3-4)\times 10^{-5}$ with at least one year of data.

Test of gravitational redshift with Galileo 5 and 6

An **elliptic orbit** induces a **periodic modulation** of the gravitational part of the relative frequency difference between a ground clock and the satellite clock $y = -\frac{GM}{c^2 r_s}$, while the good stability of recent GNSS clocks allows to test this periodic modulation to a very high level of a accuracy. The Galileo 5 and 6 satellites, with their large eccentricity and on-board H-maser clocks, are hence perfect candidates to perform this test. Contrary to GP-A experiment, it is possible to integrate the signal on a long duration, therefore improving the statistics.
We studied the statistical sensitivity of a gravitational redshift test performed with Galileo 5 and 6 through two very different methods: the Fast Fourier Transform (FFT) method and the Linear Least-Square (LSQ) method.





Statistical uncertainty.
Model: $\tilde{y}(\alpha) = -(1+\alpha)\frac{GM}{c^2 r_s}$

Systematic effects

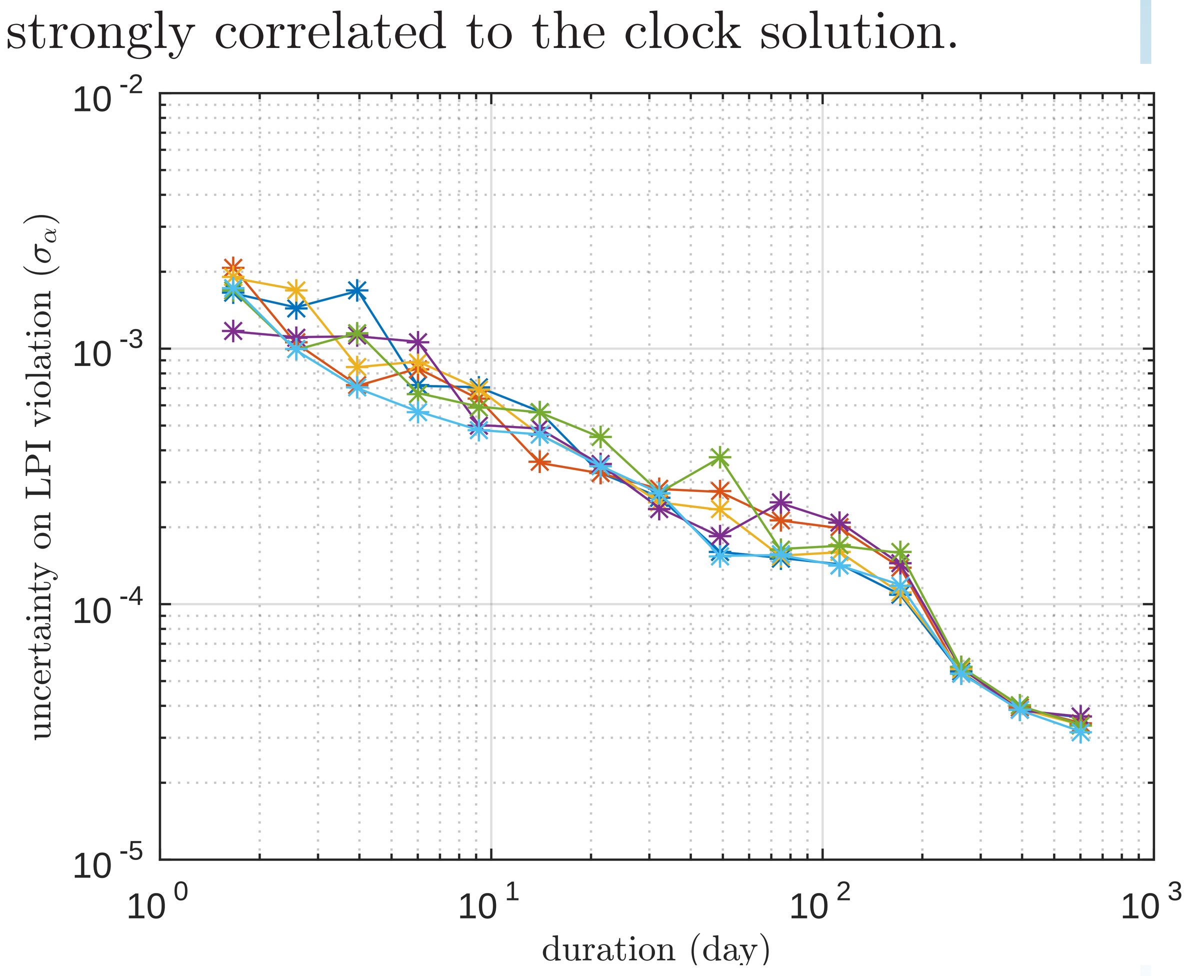
We classify systematic effects in four classes:

(i) effects acting on the frequency of the reference ground clock

(ii) effects on the links (e.g. mismodeling of ionospheric or tropospheric delays)

(iii) effects acting directly on the frequency of the space clock (e.g. temperature and/or magnetic field variations on board the Galileo satellites)

(iv) orbit modelling errors (e.g. mismodeling of Solar Radiation Pressure SRP). These are strongly correlated to the clock solution.

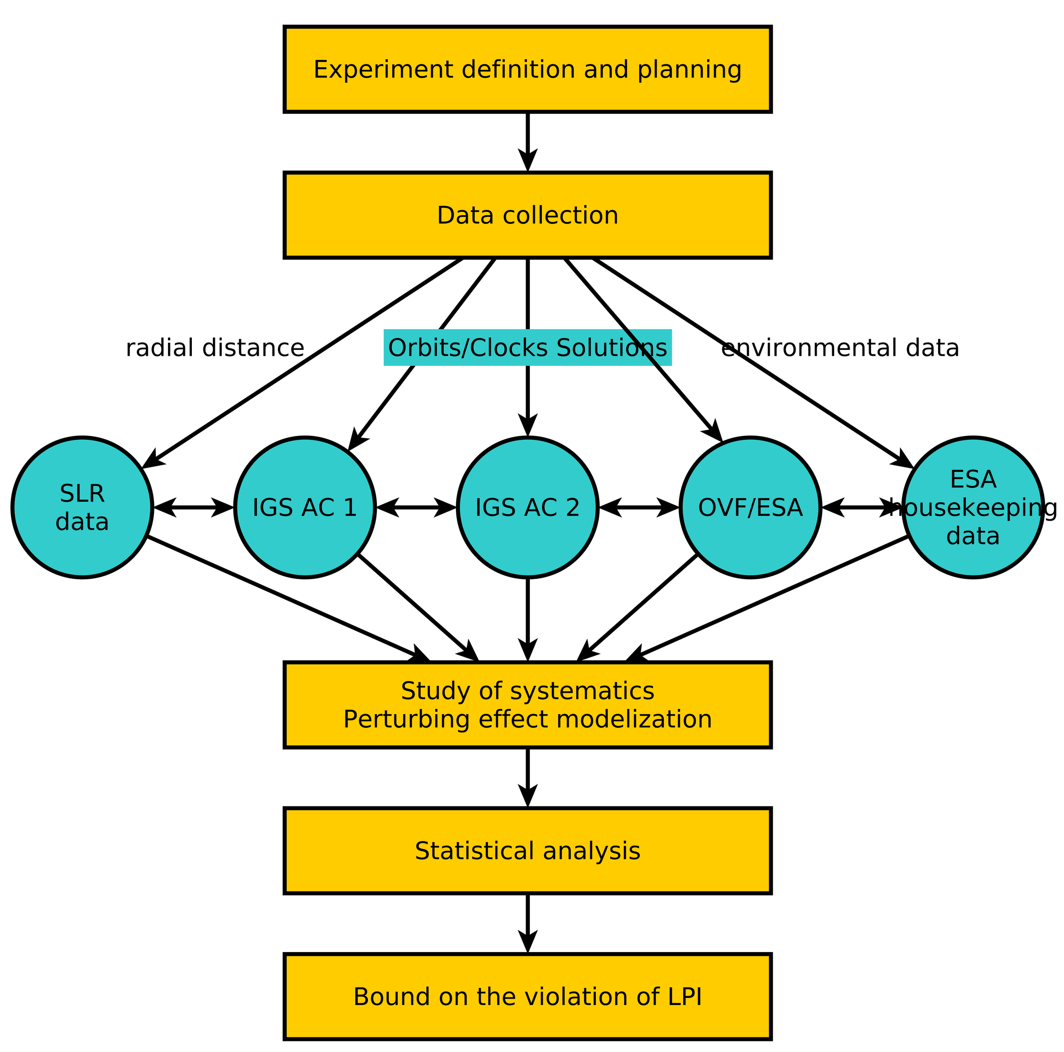


Effect of the SRP mismodeling for different clock noise

GREAT Project

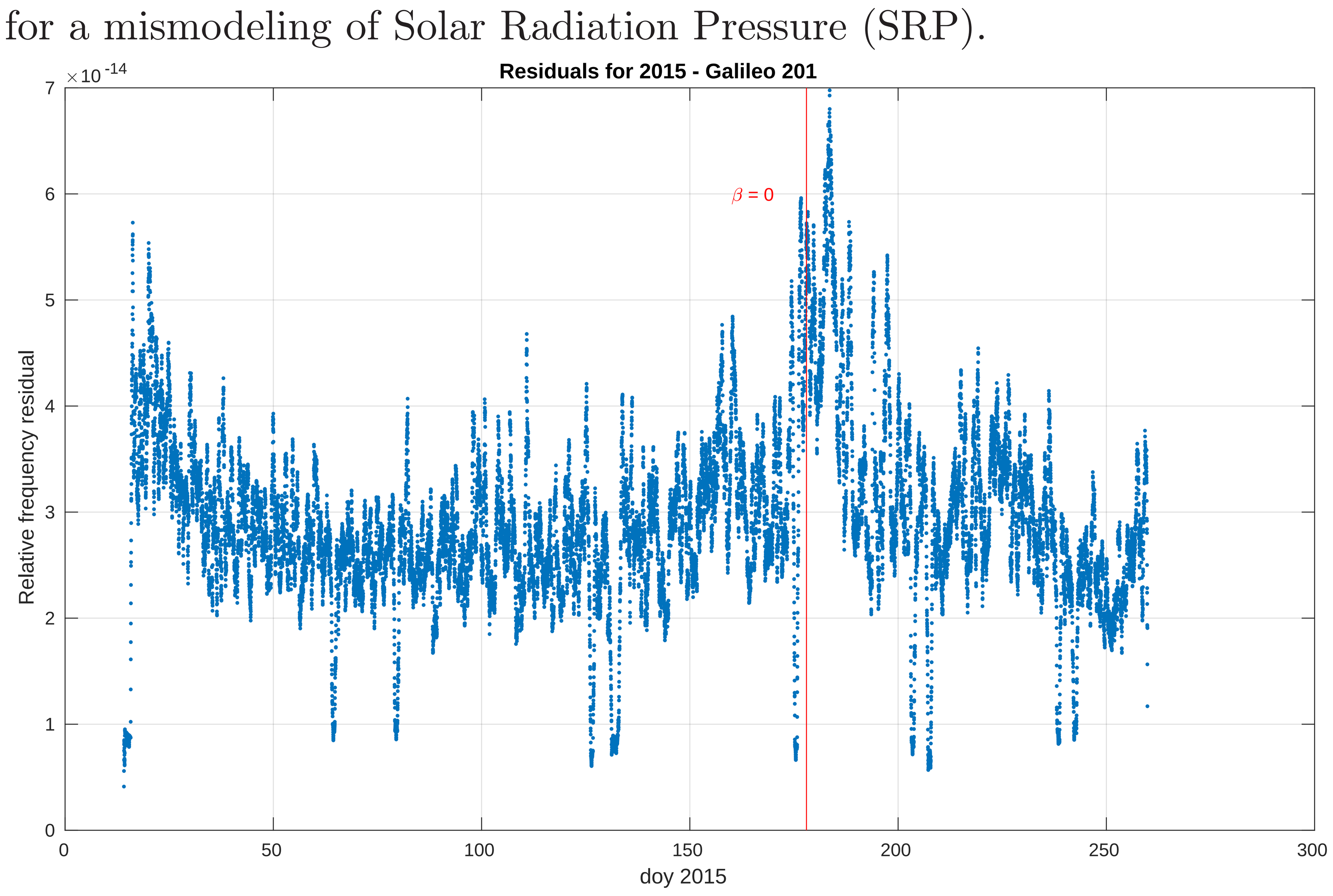
GREAT: **G**alileo gravitational **R**edshift test with **E**ccentric s**AT**ellites

ESA funded two independent studies to exploit Galileo 5 and 6 data. SYRTE is leading one of them, with the collaboration of Geoazur/OCA who started a dedicated SLR campaign on these 2 satellites. IGS and ILRS analysis centers also contribute to the project (in particular ESOC, CODE, CLS/CNES and GRGS).



Clock error dependence with the β angle

The radial part of the orbital error contributes directly to the clock estimation error. Indeed, it has been shown that the clock offset is correlated with satellite laser ranging SLR residuals, which can be considered as a measure of the radial orbit error. We have calculated the relative frequency residual for almost one year of data from the Center for Orbit Determination in Europe CODE center analysis for Galileo 5 satellite and we see that the systematic effects are linked to the direction of the Sun, as for a mismodeling of Solar Radiation Pressure (SRP).



References

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[2] Vessot, R.F.C. & Levine, M.W., A test of the equivalence principle using a space-borne clock, General Relativity and Gravitation, 1979, 10, 181-204