The ILRS campaign for the GREAT experiment

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Abstract

We use signals from Galileo satellites 5 and 6 (GAL-201 and GAL-202) to perform a test of Gravitational Redshift [1]. ESA is funding two parallel studies, named Galileo gravitational Redshift test with Eccentric sATellites (**GREAT**), led by SYRTE/Observatoire de Paris and ZARM. **ILRS supports the GREAT experiment** by initiating a one-year campaign of SLR with Galileo satellites 5 and 6. We present the current status of this campaign, and a first analysis of the SLR data in order to estimate an upper limit of the systematic effects coming from the orbital errors impacting the clock determination.

The GREAT experiment

An **elliptic orbit** induces a **periodic modulation** of the relative frequency difference between a ground clock and the satellite clock, while the good stability of recent GNSS clocks allows to test this periodic modulation to a high level of a accuracy. Galileo 5 and 6 satellites, with their large eccentricity and on-board H-maser clocks, are perfect candidates to perform this test.

ESOC produced orbit and clock solutions for the project, as well as corresponding SLR residuals. The statistical sensitivity of the gravitational redshift test is estimated thanks to a Linear Least-Square (LSQ) method. Systematic effects are not yet included in the model but an upper limit is estimated thanks to SLR.

The ILRS campaign

The stations in the ILRS network are asked to support this experiment as follows:

- The GREAT experiment started on May 1, 2016
- Stations are asked to concentrate observations during one week per month, the first 7 days of each month, over a period of one year. These 7-day periods will allow the SLR network to intensively sample the orbit on a monthly basis and still encompass the different weekly operating schedules from one station to another.
- Although the two satellites are set at their specified priorities for the entire year of the experiment, stations are asked to track the target satellite (Galileo-201) more intensively during the one week monthly period. Galileo-202 will be a secondary or backup target used if there are issues with the -201 satellite itself.
- Stations should observe each pass, sampling data from the beginning to the end, with one or two normal points about every 50 minutes.
- Normal points are a maximum of 5 minutes in duration.

Perspectives

The accuracy of the Gravitational Redshift test is (up to now) limited by the systematic uncertainty due to orbital errors, and **SLR residuals are crucial** to understand them. The next step is to study in details the SLR residuals in combination with the clock bias in order to find a good model of the systematics which will be able to decorrelate the orbital errors from the clock signal. We will also study solutions from other IGS centers with different modeling.

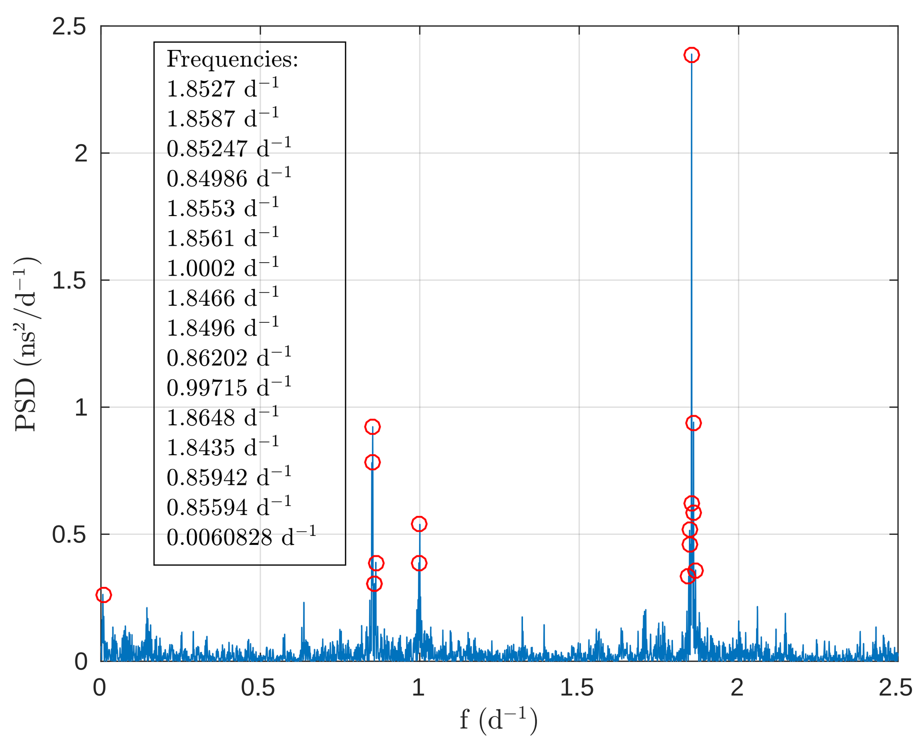
Statistics for the first six months

Galileo-201 Tracking Totals per Month

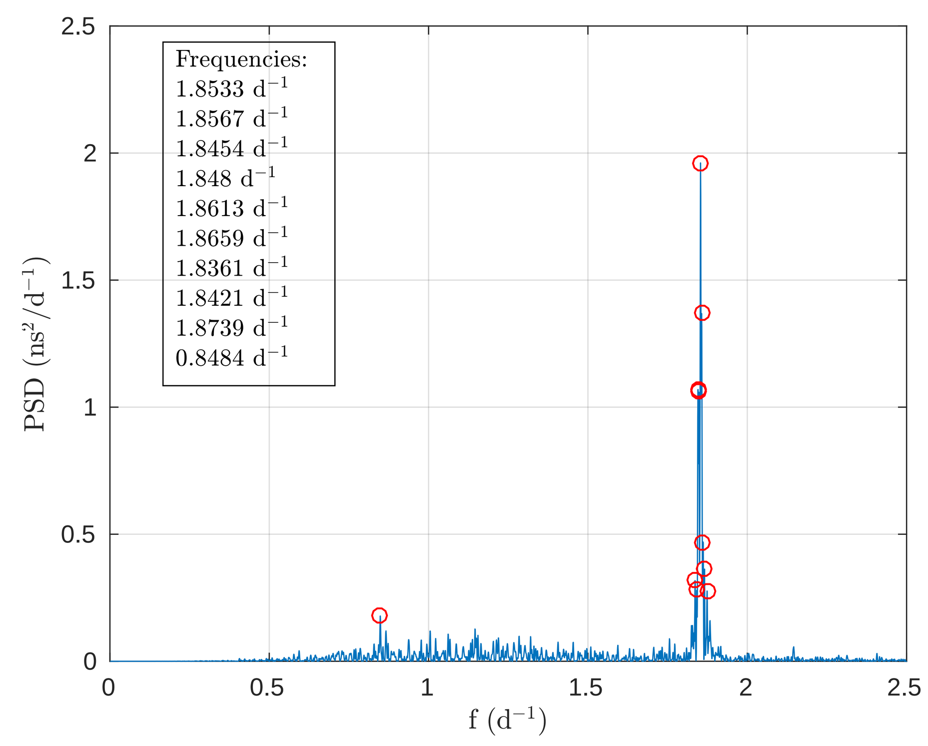
Month	Satellite	No. Passes	No. Points	No. Stations
201605	GALILEO-201	35	125	11
201606	GALILEO-201	29	118	12
201607	GALILEO-201	41	160	9
201608	GALILEO-201	41	164	9
201609	GALILEO-201	31	131	7
201610	GALILEO-201	29	115	9

Stations which are more involved are Yarragadee, Grasse, Herstmonceux, the Monument Peak, Wettzell and Matera. The good geometry and the homogeneous sampling along the passes are considered essential to study orbit systematics.

Power Spectral Density (PSD)



PSD of the SLR residuals for GAL-201

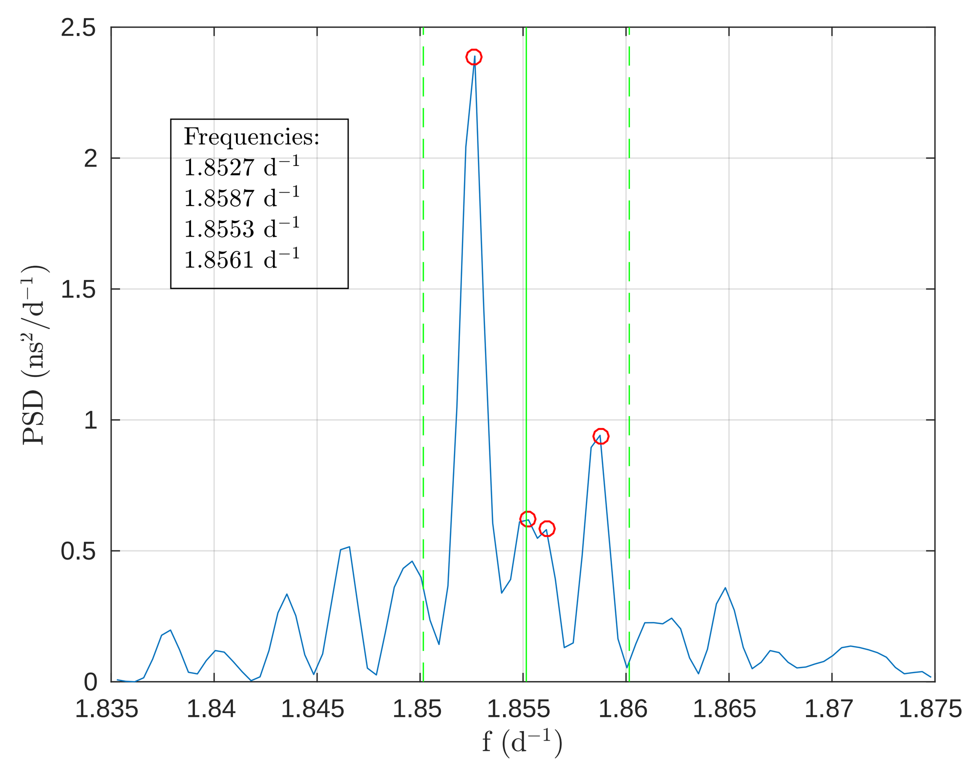


PSD of the detrented clock bias for GAL-201

Systematic effects: mismodeling of SRP

The radial part of the orbital errors contribute directly to the clock estimation. Indeed, it has been shown that the clock bias is correlated with SLR residuals, which can be considered as a measure of the radial orbital error. The main orbital error comes from mismodeling of Solar Radiation Pressure (SRP), which is linked to the direction of the Sun. This can be seen on the figure on the right where the main peak at orbital frequency is separated in two peaks separated by a frequency $f = 2/(\text{draconitic year})$. As a first and simplified approach, we have estimated in a frequency analysis an **upper limit of the SRP orbital error impact on the clock bias at the orbital frequency**:

- We integrate the SLR PSD in order to have the power P around the orbital frequency
- Assuming that the systematic orbital error is a sinusoid at the orbital frequency, this power is linked to the amplitude of the sinusoid with the formula $A = \sqrt{2P}$.



PSD centered on the orbital frequency (GAL-201). The central green line shows the orbital frequency, and the two dashed green lines show the integration window for the spectrum integration.

	P (ns^2)	A (ns)	A (cm)
GAL-201	0.0065	0.1140	3.42
GAL-202	0.0040	0.0895	2.68

References

[1] Delva, P., Hess, A., Bertone, E., Richard, E. & Wolf, P., Test of the gravitational redshift with stable clocks in eccentric orbits: application to Galileo satellites 5 and 6, Class. Quantum Grav., 2015, 32, 232003