An alternative approach for testing general relativity with eccentric Galileo satellites

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Abstract

As direct consequence of Einstein's Equivalence Principle, time runs (or clocks tick) more slowly near a massive body. This effect, named gravitational red-shift, can be detected when comparing time intervals measured by identical clocks placed at different positions in a gravitational field or when their tick rates, i.e. their frequencies, are compared. Einstein's prediction was tested to an uncertainty of $1.4 \cdot 10^{-4}$ in the Gravity Probe A (GPA) experiment performed by Vessot et al. [1].

In August 2014, due to a technical problem, the Galileo 5 and 6 navigation satellites were injected into the wrong orbit. Because of the orbit eccentricity (~0.15), the on-board atomic clocks (passive H-maser) are now experiencing a gravitational red-shift effect with a peak-to-peak amplitude of $5 \cdot 10^{-11}$. The clock stability, as low as $1 \cdot 10^{-14}$, is now opening interesting perspectives to measure the gravitational time dilation effect to an uncertainty at the GPA level or even lower.

In the context of an ESA founded project gAGE/UPS is analysing the data delivered by Galileo 5 and 6 satellites to measure the Einstein's gravitational red-shift effect. This challenge requires developing new and alternative techniques for improving the GNSS signal modelling and better handling the measurement systematics.

The guidelines of the study we are conducting are summarized next:

Raw data handling to diminish/mitigate some errors in the GNSS signals at receiver level
These errors (such as carrier phase multipath, thermal noise...) are typically below 1cm, but become more important when forming carrier phase combinations. Diffractive scintillation, which is present in the observations gathered at low latitudes and affects the Ionosphere -Free (IF) combination, must be also included.

The solution is to model these effects, when possible, or to down-weight the data when the modelling of the effect is not possible. This last point requires to carry out a long term study, for each receiver in the network, in order to define a realistic covariance matrix.

Techniques for reducing the correlation between parameters
To reduce the correlation between parameters, it is necessary to impose confident constraints on the different observables. For instance, a common solution for reducing correlations is the carrier phase ambiguity fixing. In this case, an un-differenced mode is applied: carrier ambiguities are fixed for all carrier phase data from different frequencies and different constellations used in the satellite clock estimations.

In addition, the models for the evaluation of effects, such as tropospheric delays, are being improved. This step is important to avoid incorrect modelling of these effects that, as mentioned above, would otherwise appear as a clock error.

A new technique for clock estimation
The clock solution is typically estimated from the IF combination of two carrier phases. However, this approach increases the noise by a factor 2.9 with the GPS L1/L2 frequencies and a factor 2.6 with the Galileo E1/E5a frequencies (in both cases, we assume the same noise for the 2 frequencies). With the new frequencies, it is possible to build up IF combinations involving more than two carriers and reducing the noise amplification. Still, these combinations present time varying IFBs should be carefully studied.

The proposed solution is based on a joint estimate of clock, IFBs, and ionospheric delays in the same filter, without building up IF combinations. In the case of 2 frequencies, and without implementing any ionospheric model, the result is expected be equivalent to the classical solution using IF combinations. In this context, we intend to extend the method to handle more than 2 frequencies, at the same time introducing ionospheric models. A precision measurement of the gravitational redshift will require a correct modelling of IFBs, particularly of their dependence with temperature.

Long term study of the clock solutions

Once the satellite clock biases are estimated, the final task is to infer the gravitational red-shift signature in the satellite clock values. This will done using long term series (∼1 year) of satellite clock estimations.

References

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