Summary of Scientific Results from the GREAT Experiment

Galileo satellites 5 (GSAT0201) and 6 (GSAT0202) launched in August 2014, were stranded in incorrect orbits by a malfunctioning of the Soyuz rocket upper stage. Flight controllers from the European Space Agency (ESA) performed a daring salvage in space to raise the low points of the satellites' orbits and make them more circular. However, their orbits remained highly elliptical, with each satellite climbing and falling some 8500 km twice per day. This high eccentricity, though, became a unique opportunity to conduct an advanced test of local position invariance, an integral part of the Einstein equivalence principle, improving one of the long-standing classical test of General Relativity: the gravitational redshift test of Gravity Probe A rocket, launched in 1976.

Identifying this unique scientific opportunity, ESA launched a dedicated research activity with two independent research groups, led respectively by the SYRTE Observatoire de PARIS -PSL in France and Germany's ZARM Center of Applied Space Technology and Microgravity, coordinated by ESA's Galileo Navigation Science Office and supported through ESA Basic Activities. These projects, named GREAT (Galileo gravitational Redshift Experiment with eccentric sATellites) analysed the equivalent of about 1000 days of data from the two eccentric Galileo satellites, allowing measured the gravitational redshift with unprecedented accuracy.

These extraordinary results have been made possible thanks to the unique features of the Galileo satellites, notably the very high stabilities of their on-board atomic clocks, the accuracies attainable in their orbit determination and the presence of laser-retroreflectors.

A key challenge of this research was to model and bound systematic effects such as clock error and orbital drift due to factors such as the influence of Earth's magnetic field, temperature variations and the solar radiation pressure effect in the orbits. In this context, the support from the International Laser Ranging Service (ILRS) proved essential. Indeed, a specific ILRS campaign took place during the years 2016-2017, supporting a dedicated ranging campaign for the satellites GSAT-0201/0202. These laser ranging measurements allowed to measure very precisely the radial one-way residuals with respect to the modelled orbit solution from the observed data, which, in turn, allowed to quantify the systematics due to the orbital modelling in order to obtain a robust error budget.

By analyzing this Galileo tracking data, the two ESA supported European research teams managed, independently, to improve on the Gravity probe A test (1976) of the gravitational redshift by a factor around 5. Providing, to our knowledge, the first reported improvement since more than 40 years, becoming today the most accurate reference for this General relativity test.

These outstanding scientific results were published by the prestigious Physical Review Letter in two dedicated articles in December 2018:

S. Hermann et al. "Test of the gravitational redshift with Galileo satellites in an eccentric orbit," *Physical Review Letters, Vol. 121, Iss. 23, p. 231102, 7 December 2018.*

P. Delva et al. "A gravitational redshift test using eccentric Galileo satellites" *Physical Review Letters, Vol. 121, Iss. 23, p. 231101, 7 December 2018*

The GREAT team expresses their sincere gratitude to the ILRS community and the ILRS Central Bureau for having coordinated the ILRS support to this activity. The support from the ILRS proved essential in achieving their outstanding scientific results, allowing them to determine very precisely the radial one-way residuals with respect to the modelled orbit solution from the observed data, which, in turn, allowed to disentangle the desired red-shift signals from systematics due to the orbital modelling. Throughout this activity the group has managed to improve (results obtained by 2 independent research teams) by a factor of 5 one of the long-standing classical test of General Relativity: the gravitational redshift test of Gravity Probe A rocket, launched in 1976. To our knowledge this is the first reported improvement since more than 40 years, becoming today the most accurate reference for this classical General relativity test.

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