An SLR campaign on Galileo satellites 5 and 6 for a test of the gravitational redshift – the GREAT project

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2015 ILRS Technical Workshop

Matera, Italy, October 26–30, 2015

Outline

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Motivation: a quantum theory of gravitation

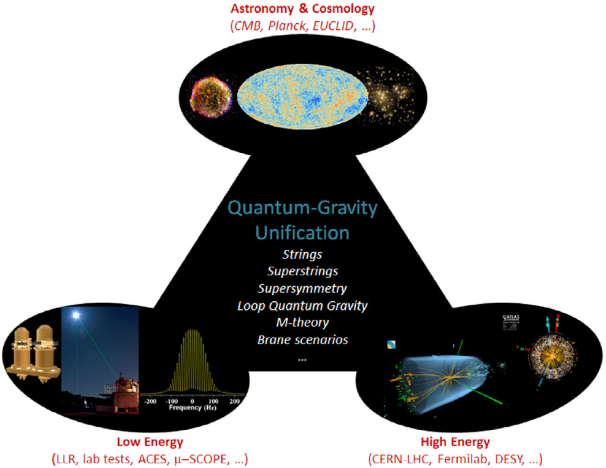
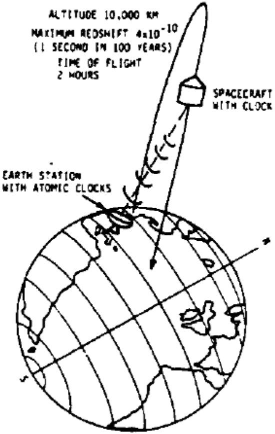


Figure from [Altschul et al., 2015].

Gravitational redshift test: Gravity Probe A (GP-A) (1976)



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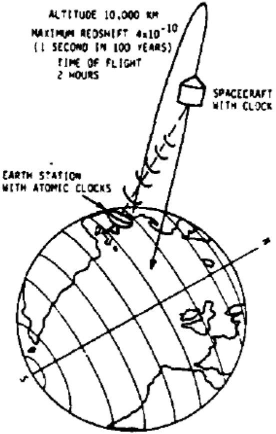

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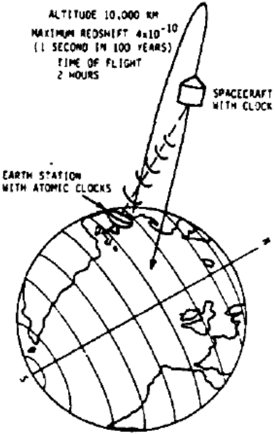

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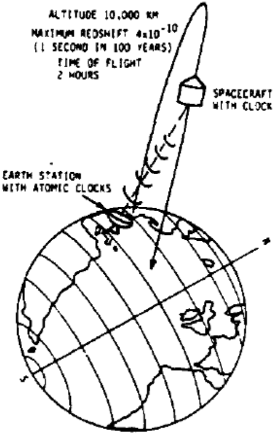

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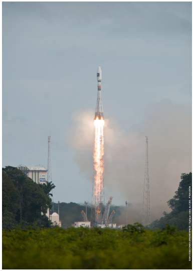
The story of Galileo satellites 5&6

- Galileo satellites 5 and 6 were launched with a Soyuz rocket on 22 august 2014 on the wrong orbit due to a technical problem
- Launch failure was due to a temporary interruption of the joint hydrazine propellant supply to the thrusters, caused by freezing of the hydrazine, which resulted from the proximity of hydrazine and cold helium feed lines.



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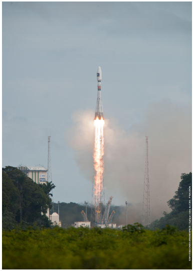
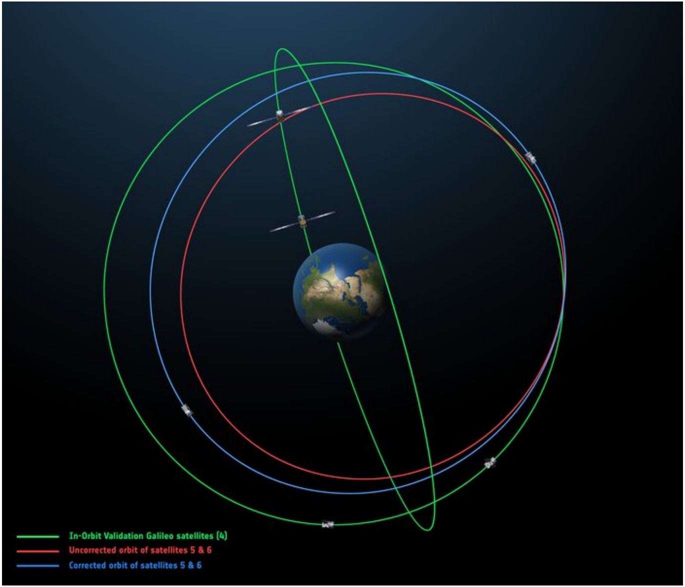


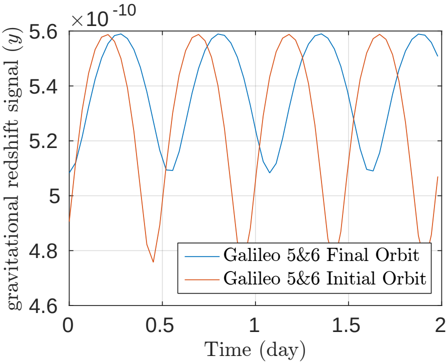
Galileo satellites 5&6 orbit



Why Galileo 5&6 are perfect candidates for a redshift test?

- An elliptic orbit induces a periodic modulation of the gravitational redshift at orbital frequency

$$y = -\frac{GM}{c^2 r_s}$$



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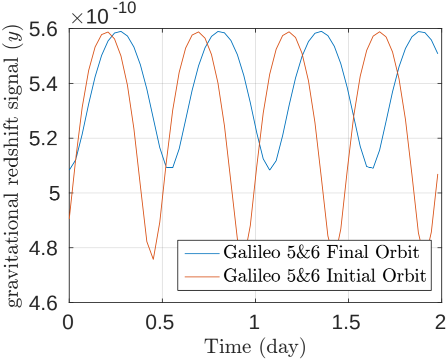

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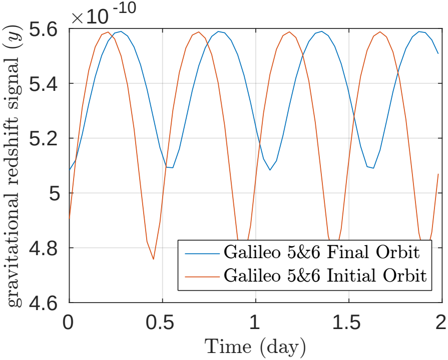

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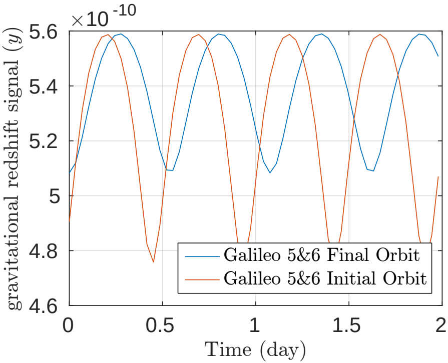

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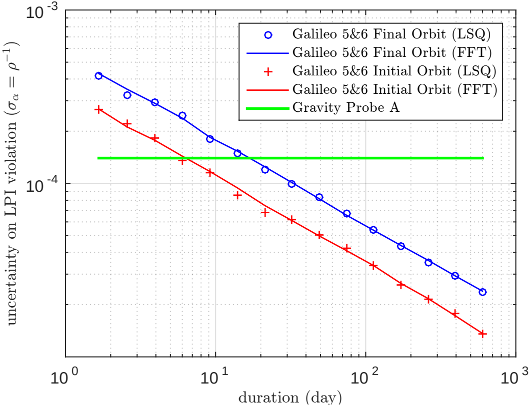
Estimation of the statistical sensitivity of the test

[Delva et al., 2015] *Test of the Gravitational Redshift with Stable Clocks in Eccentric Orbits: Application to Galileo Satellites 5 and 6*, accepted in **Classical and Quantum Gravity** (Arxiv 1508.06159).



Uncertainty of the LPI violation with respect to the duration of the experiment, considering realistic colored noise for the clock.

Limitations: systematic errors [Delva et al., 2015]

1. Effects acting on the frequency of the reference ground clock → can be safely neglected
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Condidering systematic errors, we have shown that Galileo 5 and 6 can improve on the GP-A (1976) limit on the gravitational redshift test, down to an accuracy of $(3-4)\times 10^{-5}$ with at least one year of data.

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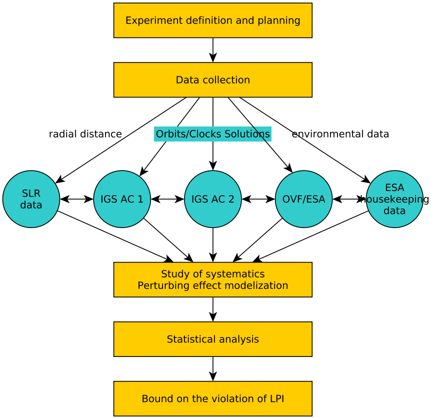
Overview of the GREAT activity



GREAT: Galileo gravitational Redshift test with Eccentric sATellites
(project funded by ESA)

Work Breakdown Structure

1. Definition and planning of the experiment, identification of requirements and input data;
2. Data collection and analysis
3. Scientific data analysis, results, recommendations and dissemination

Satellite Laser Ranging (SLR)

- SLR data is essential to characterize orbital radial errors $\rightarrow$ highly correlated to clock errors in the IGS solutions
- One year dedicated campaign of SLR data on Galileo satellites 5 and 6 planned with Geoazur/Observatoire de la Côte d'Azur (2016)

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GALILEO CONSTELLATION Weekly Tracking Report

Sat	Station	PAD	Wave	ALL Passes	ALL Points	21-SEP-2015 28-SEP-2015 Passes	Points
GAL-201	Komsomol	1868	5320	1	3		
GAL-201	Simeiz	1873	5320	3	10		
GAL-201	Mendelee	1874	5320	3	11		
GAL-201	Altay	1879	5320	1	3		
GAL-201	Mcdonald	7080	5320	7	20		
GAL-201	Yarragad	7090	5320	117	316	1	3
GAL-201	Greenbel	7105	5320	29	80		
GAL-201	Monument	7110	5320	34	85		
GAL-201	Tahiti	7124	5320	5	20		
GAL-201	Changchu	7237	5320	85	200		
GAL-201	Beijing	7249	5320	8	27		
GAL-201	Hartebee	7501	5320	3	9		
GAL-201	Zimmerwa	7810	5321	32	83	2	4
GAL-201	Shanghai	7821	5320	13	49		
GAL-201	Mt Strom	7825	5321	66	329	2	4
GAL-201	Graz	7839	5320	49	212	1	5
GAL-201	Herstmon	7840	5320	54	170	3	10
GAL-201	Potsdam	7841	5321	7	36	1	5
GAL-201	Grasse	7845	5321	5	20		
GAL-201	Matera	7941	5320	78	231	2	5
GAL-201	Wettzell	8834	5320	70	284	1	4
				670	2198	13	40

SLR data vizualisation tool

period from : 2015-09-21

to : 2015-09-28

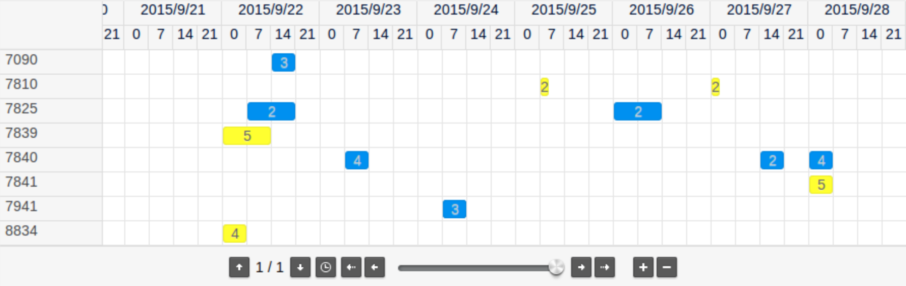
satellite : galileo201

stations : (multiple choice with Ctrl-Click)

- 7090 Yarragadee
- 7810 Zimmerwald
- 7825 Mt Stromlo STL3
- 7839 Graz
- 7840 Herstmonceux
- 7841 Potsdam
- 7941 Matera MLRO
- 8834 Wettzell

Data Table | Visibility Graph

Station	File	Start		End		Nbr Mes
7090	galileo201_20150923.npt	2015/09/22	16:02:15	2015/09/22	16:11:35	3
7810	galileo201_20150926.npt	2015/09/25	12:48:15	-1/-1/-1	-1:-1:-1	2
	galileo201_20150927.npt	2015/09/27	01:29:18	-1/-1/-1	-1:-1:-1	2
7825	galileo201_20150921.npt	2015/09/20	04:05:17	2015/09/20	10:26:24	3
	galileo201_20150923.npt	2015/09/22	08:47:34	2015/09/22	16:20:38	2
	galileo201_20150928.npt	2015/09/26	02:27:41	2015/09/26	08:24:00	2
7839	galileo201_20150921.npt	2015/09/18	11:00:00	2015/09/18	16:28:00	11
	galileo201_20150923.npt	2015/09/22	04:04:00	2015/09/22	08:24:00	5
7840	galileo201_20150924.npt	2015/09/23	07:58:30	2015/09/23	08:56:50	4
	galileo201_20150928.npt	2015/09/27	18:08:29	2015/09/27	18:10:49	2
		2015/09/28	04:33:18	2015/09/28	05:16:57	4



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Literature I

Altschul, B., Bailey, Q. G., Blanchet, L., Bongs, K., Bouyer, P., Cacciapuoti, L., Capozziello, S., Gaaloul, N., Giulini, D., Hartwig, J., Iess, L., Jetzer, P., Landragin, A., Rasel, E., Reynaud, S., Schiller, S., Schubert, C., Sorrentino, F., Sterr, U., Tasson, J. D., Tino, G. M., Tuckey, P., and Wolf, P. (2015).
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