Measuring the Lense-Thirring effect with Galileo?

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Outline

1. Introduction
2. Simulation of Galileo orbits with EPOS-OC
3. Optimal parameterization for the LT effect estimation
4. Effects of the mismodelling in the SRP on the LT estimation
5. Conclusions

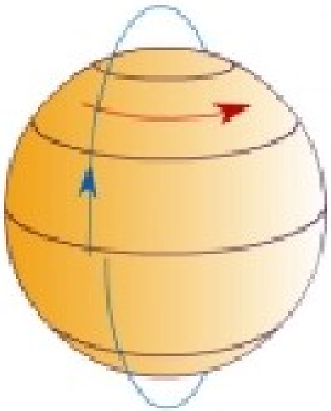
Introduction

- The G. R. predicted that a spinning mass should drag inertial frames along with it.
- Lense and Thirring (1918) proved that a test particle, orbiting around a central body endowed with angular momentum J, experiments a **nodal precession**

$$\dot{\Omega} = \frac{2GJ}{c^2 a^3 (1-e^2)^{3/2}}$$

a = particle semimajor axis

e = orbit eccentricity

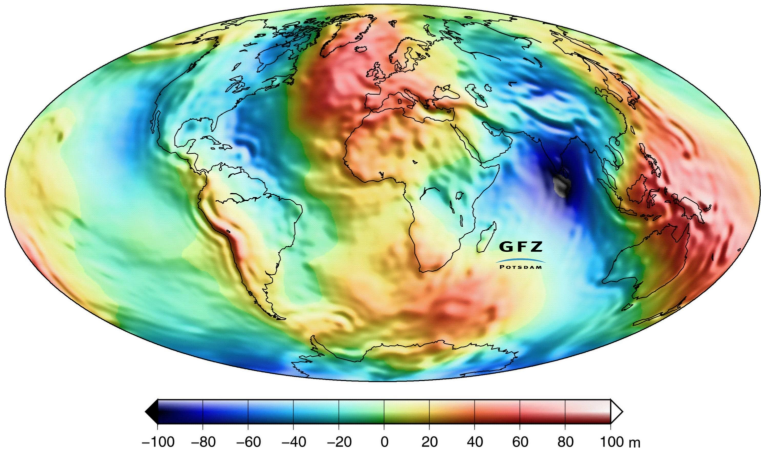


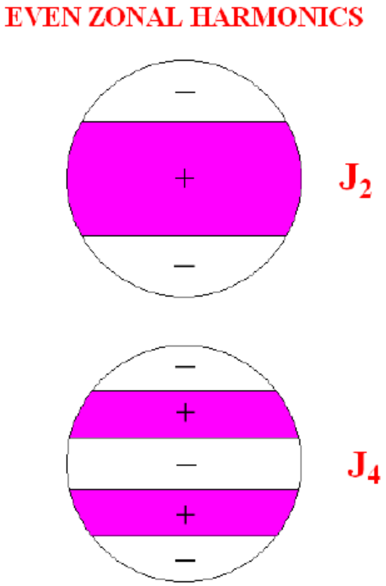
Embacher, 2012

- Nowadays the LT effect has already been measure with a good accuracy with the help of artifitial satellites

Introduction

The main error in the measurement of the frame-dragging using the nodes of an Earth satellite is due to the **uncertainties in the Earth's gravity field model**





Due to the **high accuracy** of the latest Earth's gravity field models based on **GRACE** data, the error due to the even zonal harmonics has been reduced to a few % (Ciufolini et al., 2010).

Introduction

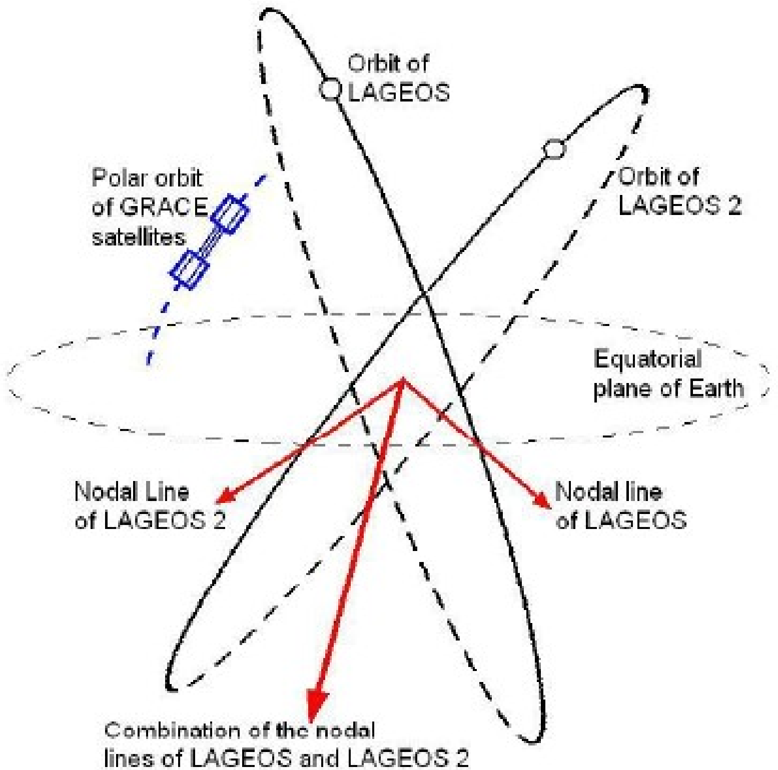
LAGEOS and LAGEOS 2

Combining two observable quantities provided by the 2 nodes of LAGEOS and LAGEOS 2, the error due to δJ2 cancels out

$$\dot{\Omega}_1 + k\,\dot{\Omega}_2 = 31 + k\,31.5\,mas/yr$$
$$= 48.2\,mas/yr + errors$$

k = 0.545

Then, the LT has been measured with an uncertainty of 10% (Ciufolini et al., 2011)



http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/lag1_general.html

Introduction

LARES (LAser RElativity Satellite)

The combination of LAGEOS, LAGEOS 2 and LARES allows to remove the uncertainty in J2 and J4

$$\dot{\Omega}_1 + k\,\dot{\Omega}_2 + q\,\dot{\Omega}_3 = 31 + k\,31.5 + q\,118 + errors \ \ mas/yr$$

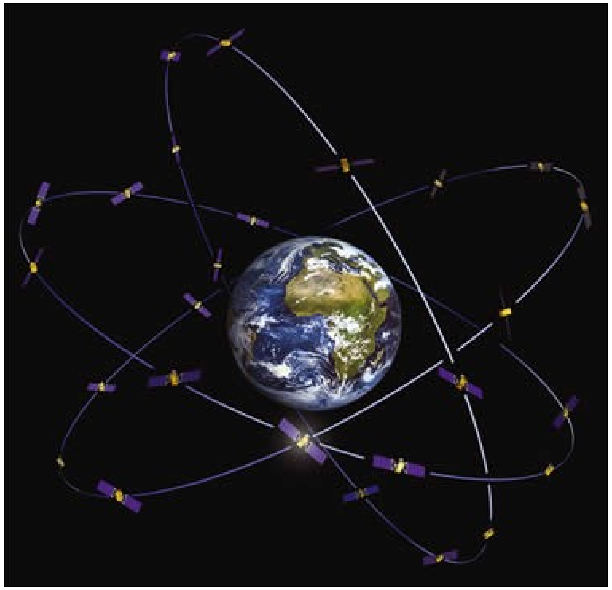
http://www.lares-mission.com/

Then, the LT effect can be measured with an uncertainty of 1% (Ciufolini et al., 2011)

Introduction

Galileo

- Galileo will provide **27 new node observables** for the LT effect estimation
- Their combination with the LAGEOS and LARES satellites will reduce the error introduced by the Earth's even zonal harmonics.



http://www.esa.int/esaNA/galileo.html

- No resonance with Earth rotation
- SLR retro-reflectors on board

Problems:

(1)The estimation of parameters in the orbit determination can absorb part of the LT effect.

(2)The accuracy in the determination of the Galileo orbits is limited mainly by the **mismodeling of the Solar Radiation Pressure (SRP)**.

2. Simulation of Galileo orbits with EPOS-OC

Different sets of Galileo orbits has been simulated with EPOS-OC (Earth Parameter and Orbit System – Orbit Computation)

Solar Radiation Pressure (SRP) modelling in EPOS-OC

$$\ddot{\vec{r}} = \left[\frac{A}{R}\right]^2 \frac{1}{m} F_{rad} \frac{\vec{R}}{R}$$

$A:\ AU\ (m)$ $m:\ satellite\ mass\ (kg)$
$\vec{R}:\ satellite\ heliocentric\ radius\ vector\ (m)$
$F_{rad}:\ ROCK4\ model\ (Fliegel\ et\ al.,\ 1992)$

→ ROCK4 model is fitted to GPS satellites features

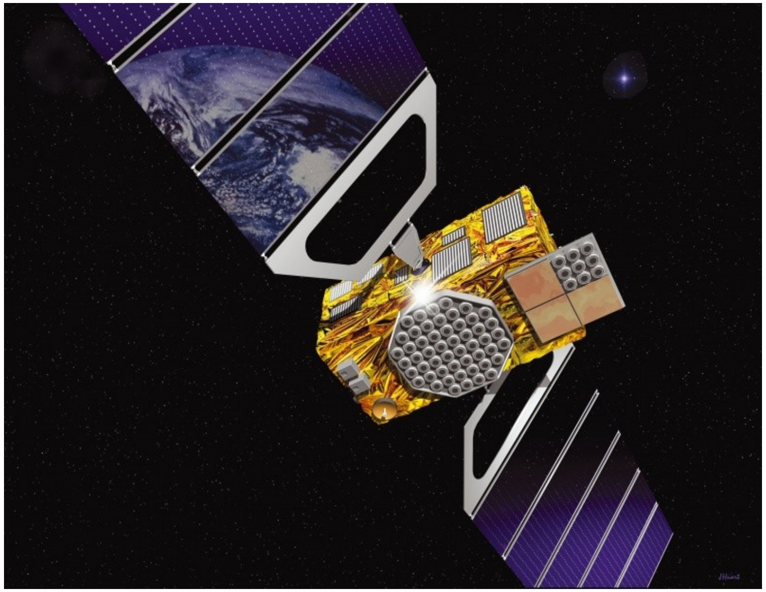
$F0:\ global\ scaling\ factor$
$X, Y, Z - biases$

2. Simulation of Galileo orbits with EPOS-OC

Solar Radiation Pressure (SRP) modelling in EPOS-OC

- Galileo vehicle characteristics:
  - Size, weight, surface properties
- Attitude steering
- Maneuvers (duration, size)
- better SRP model (macro model)

Bus dimensions	2.7 x 1.1 x 1.2 m
Solar array span	13 m
mass	700 kg



ESA, 2012

2. Simulation of Galileo orbits with EPOS-OC

Galileo orbits:

- **27 Galileo satellites**
- Walker 27/3/1 configuration
- a=29600 Km, e=0, i=56 deg (ESA 2012)
- **Observations (code and phase)** in a global network of 80 stations

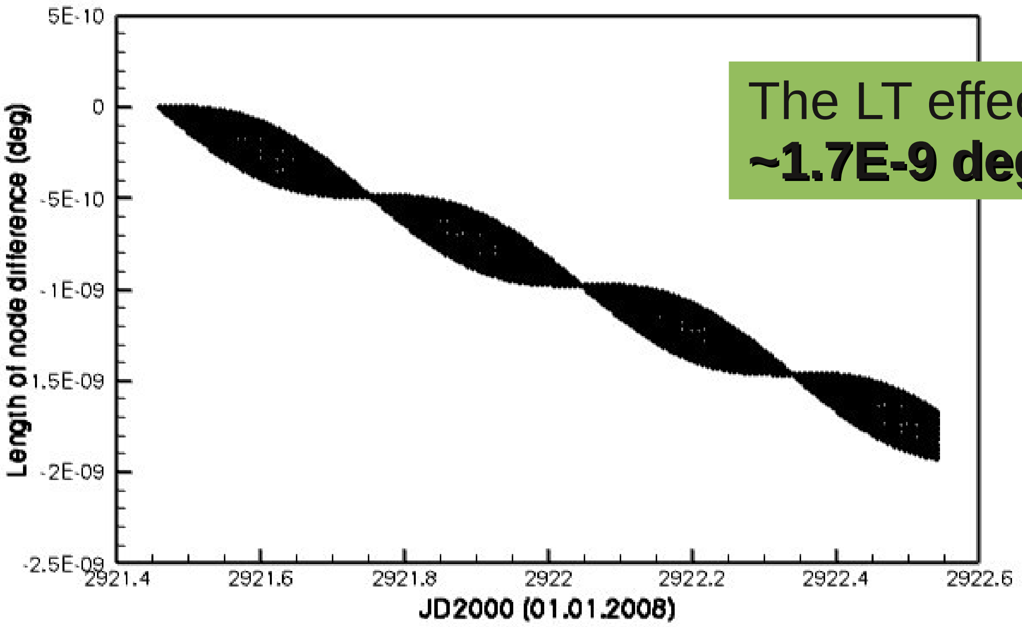
Models used in the simulation of Galileo orbits	
Gravity field	EIGEN-6C 12x12
Earth tide	IERS Conventions 2010
Ocean tide	EOT11a
Atmospheric tide	Bode-Biancale, 2003
Lunisolar and planetary perturbations	JPL DE421
Ocean pole tide	Desai, 2002
EOP	EOP08C04
Nutation and precession	IERS Conventions 2010

3. Optimal parameterization for the LT effect estimation

Zero case: expected LT effect

Simulated orbits with and without LT effect

Nodes position of the Simulated Galileo orbits with and without LT effect

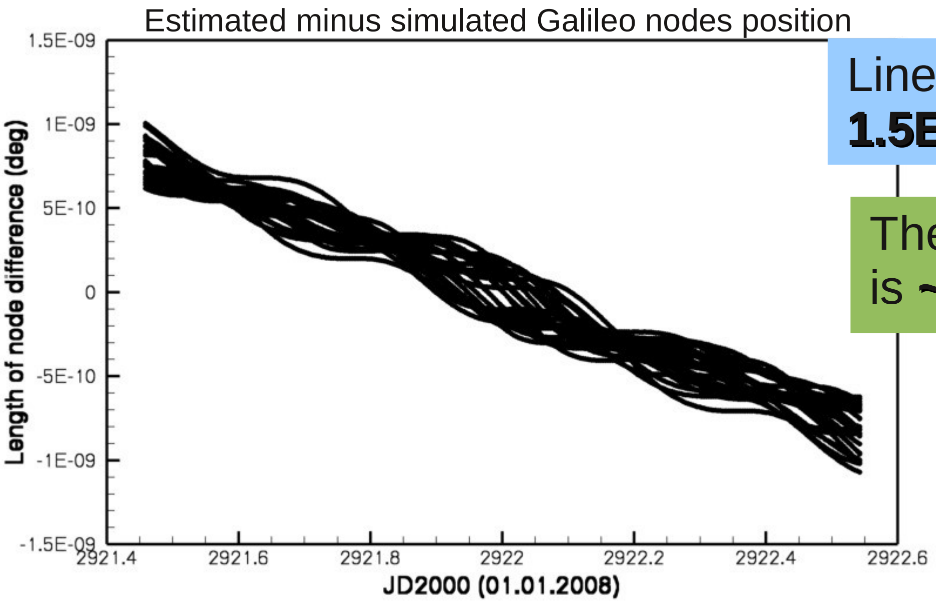


The LT effect for Galileo is
~1.7E-9 deg/d (1 mm/d)

3. Optimal parameterization for the LT effect estimation

Optimal parameterization for 1-day arcs:

- Station coordinates must be either fixed or constrained with NNT-NNR-NNS conditions
- The estimation of the normal components of empirical forces absorbs the LT effect



Linear regression:
1.5E-9 ± 3E-12 deg/d

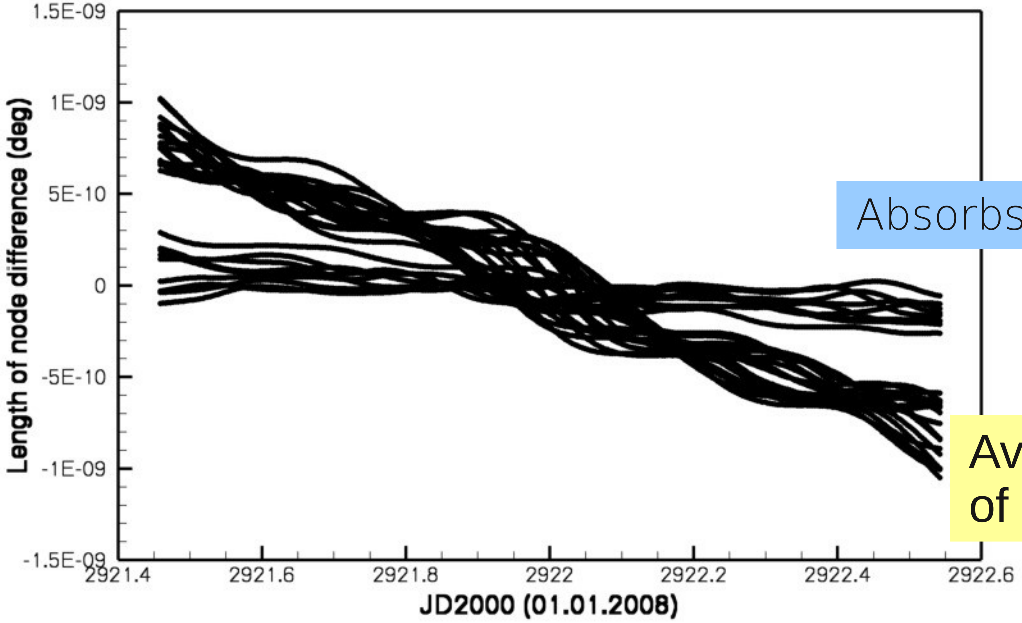
The LT effect for Galileo is **~1.7E-9 deg/d**

Optimal parameterization for 1-day arcs

3. Optimal parameterization for the LT effect estimation

Additional estimation of the SRP X-bias

Estimated minus simulated Galileo nodes position



Absorbs the LT signal

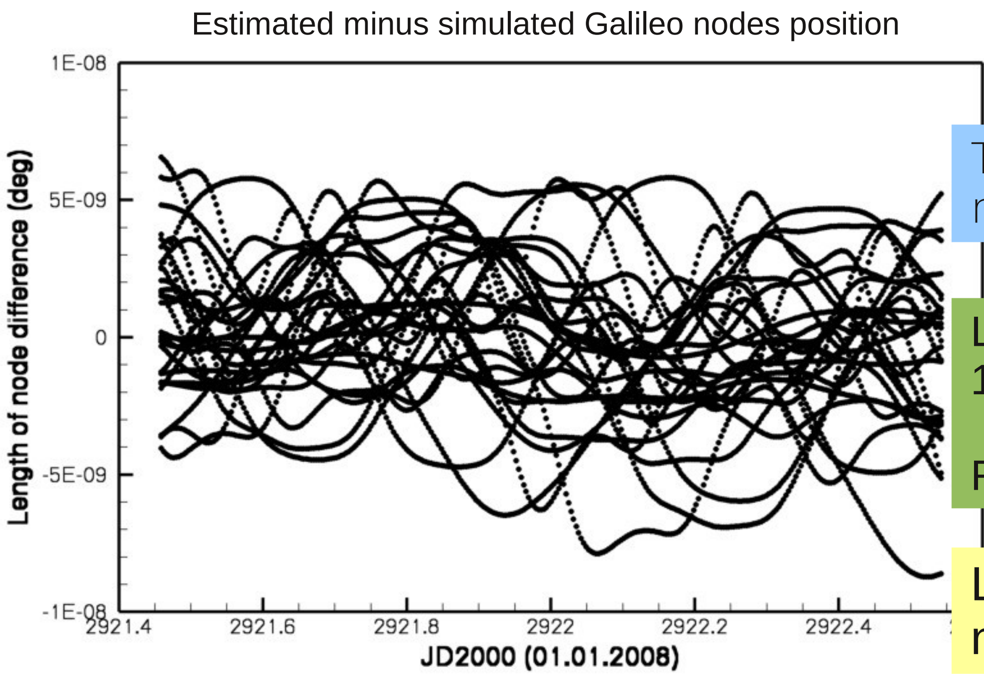
Avoid estimation of X-bias

3. Optimal parameterization for the LT effect estimation

Orbital node estimation from noisy observations

Code: 50 cm

Phase: 3 mm



The LT signal is not observed

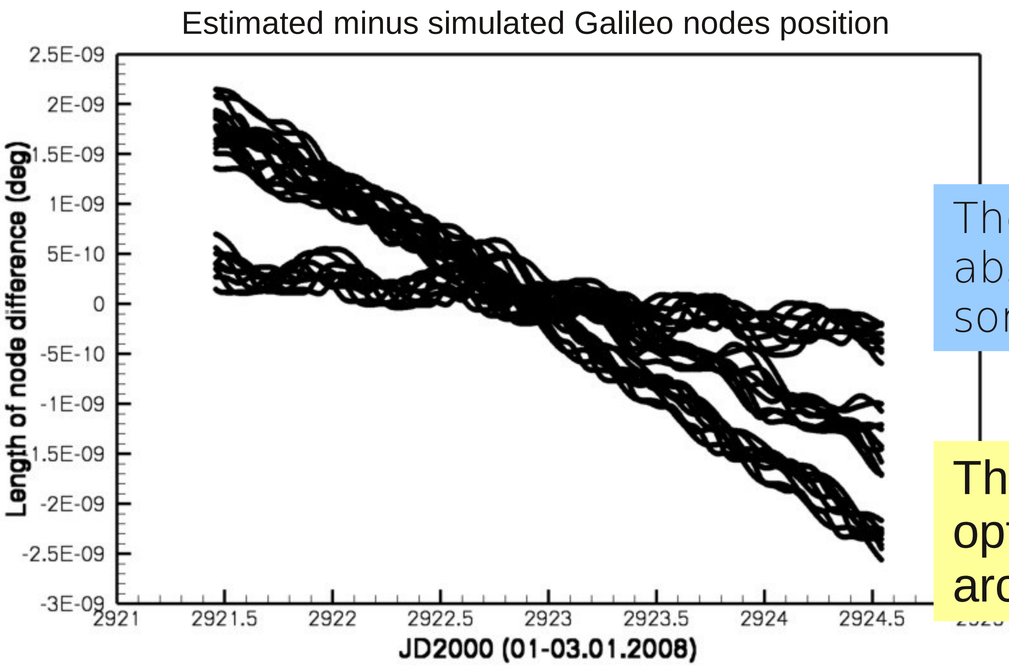
Linear regression:
1.3E-9 ± 3E-11 deg/d

RMS: **2.7E-9 deg**

Longer arcs are needed → 3 days

3. Optimal parameterization for the LT effect estimation

Optimal parameterization for 1-day arcs with 3-days arcs



The LT signal is absorbed for some satellites

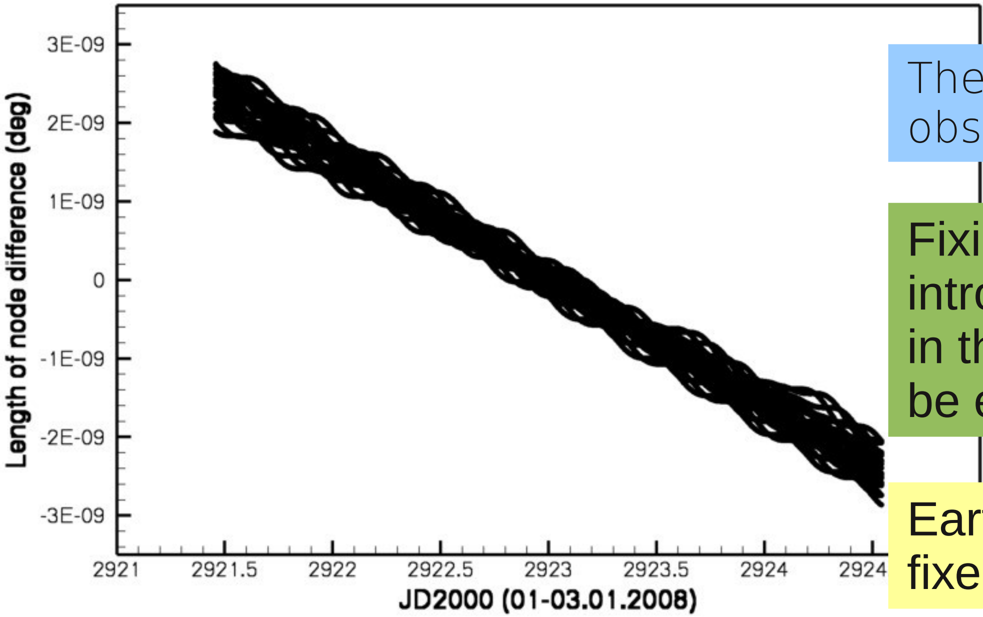
This param. is not optimal for 3-days arcs

Note:
Noise free data are used

3. Optimal parameterization for the LT effect estimation

Fixing of either Y-bias or the Earth's albedo

Estimated minus simulated Galileo nodes position



The LT signal is again observed

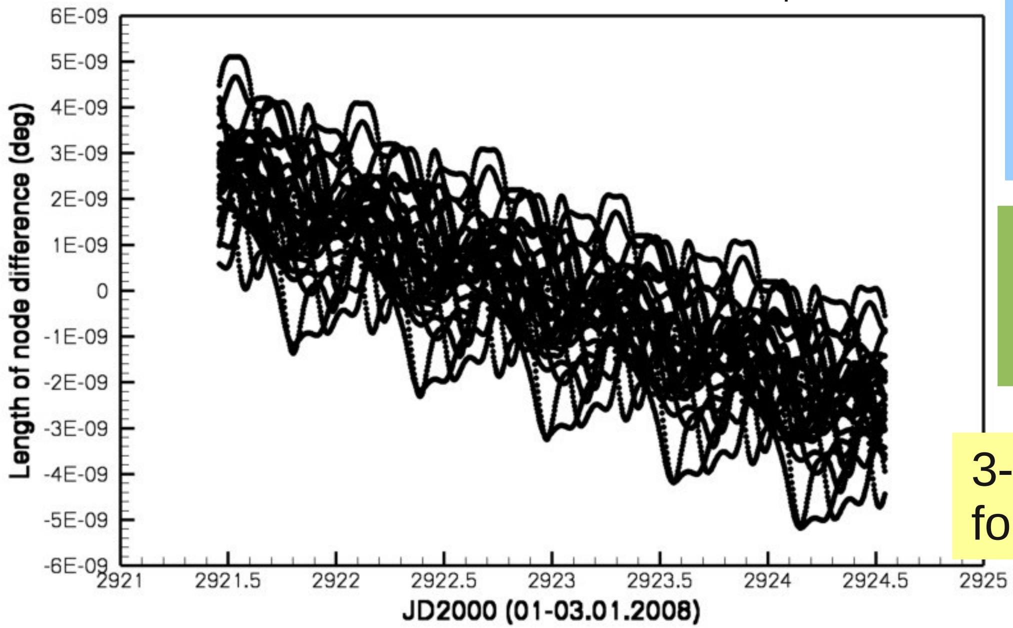
Fixing the Y-bias can introduce large errors in the node and must be estimated

Earth's albedo must be fixed

3. Optimal parameterization for the LT effect estimation

Optimal parameterization for 3-days arcs and noisy data

Estimated minus simulated Galileo nodes position



Linear regression:
1.7E-9 ± 8E-12 deg/d

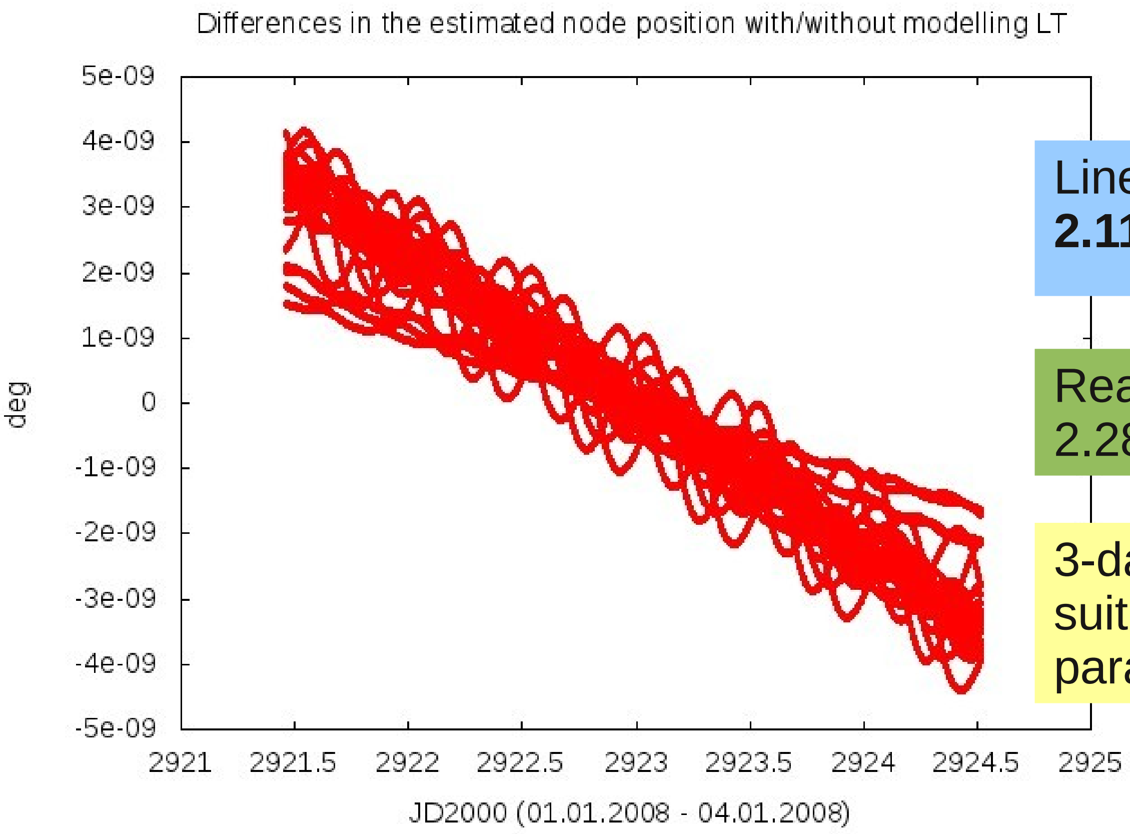
Post-fit RMS = 1E-9 deg

The total variation in 3 days is **~5E-9 deg** with precision of **1E-9 deg**

3-days arcs seem suitable for the estimation of LT

3. Optimal parameterization for the LT effect estimation

Real GPS observations



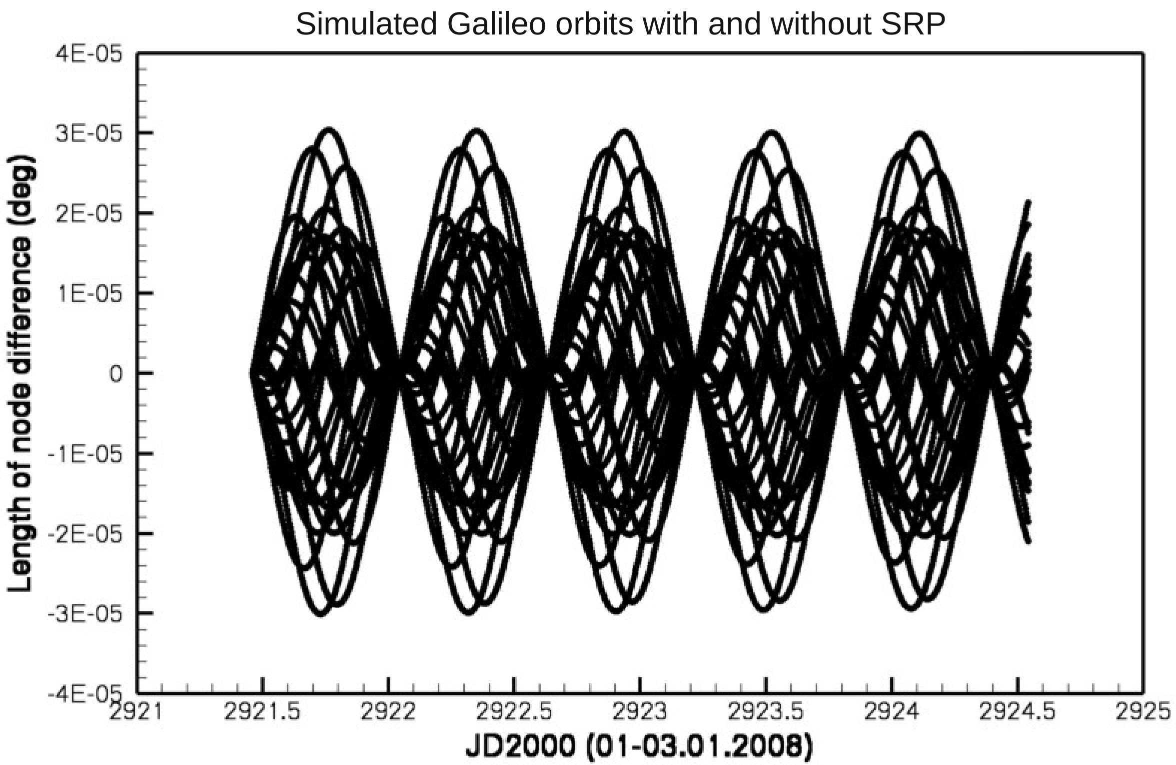
Linear regression:
2.11E-9 deg/d

Real LT for GPS:
2.28e-9 deg/d

3-days arcs are suitable and this param. is optimal

4. Effects of the mismodelling in the SRP on the LT estimation

Variation of the node position due to the SRP: F0 = 0/ F0 = 1



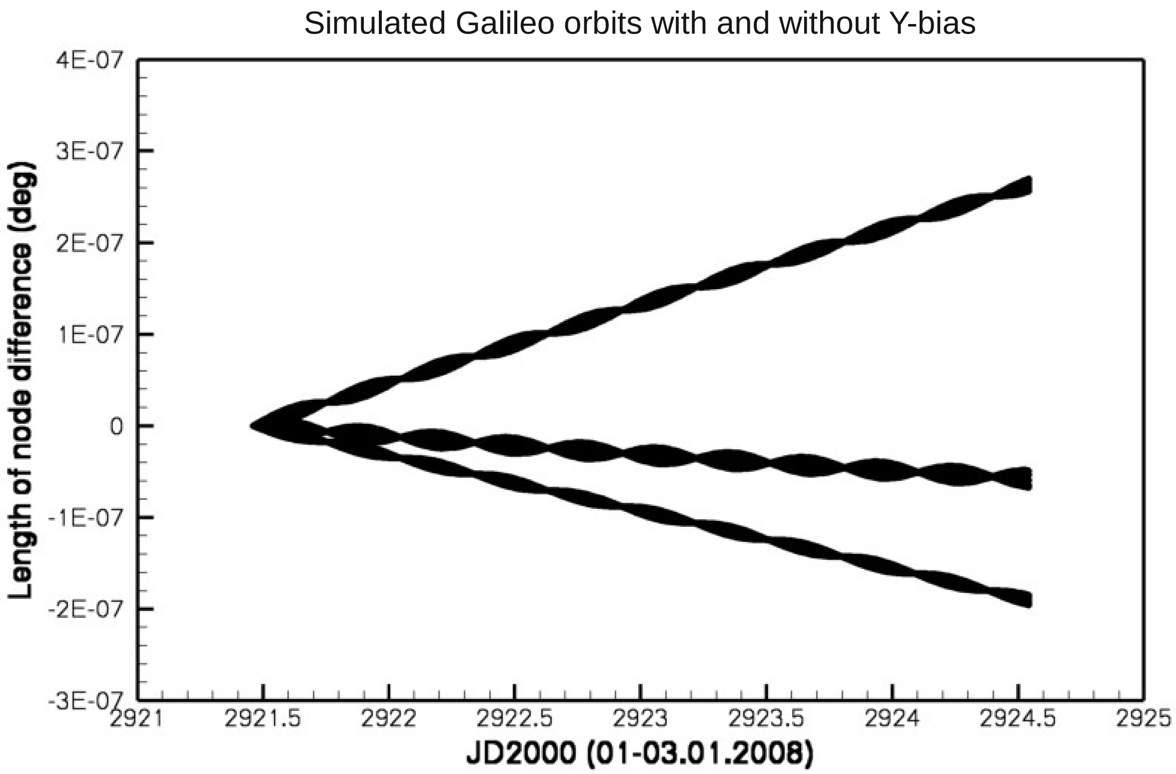
Error: **3E-5 deg**

14 h period
No trend

Z-bias: similar results than F0 but smaller

4. Effects of the mismodelling in the SRP on the LT estimation

Variation of the node position due to the **Y-bias = 1E-10**

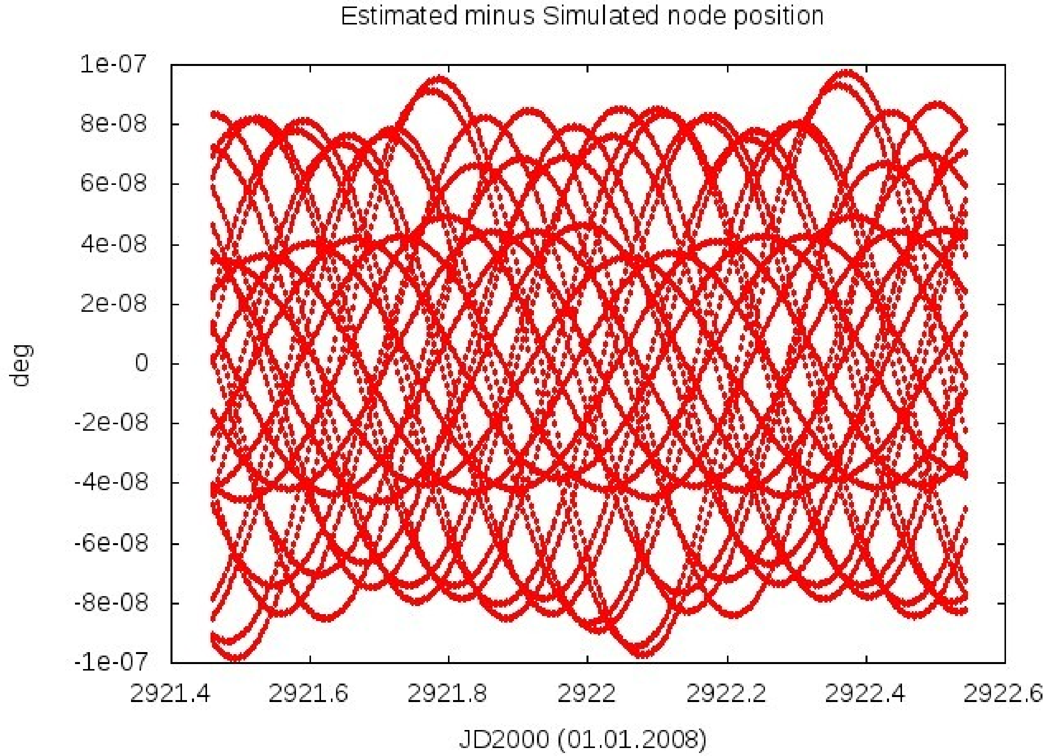


No period
Large trend:
Up to **1E-7 deg/d**

Similar results obtained with the X-bias

4. Effects of the mismodelling in the SRP on the LT estimation

Error in the **estimated node position** due to a mismodelling of **20%** in the satellite mass or area



Mismodelling of a 20%

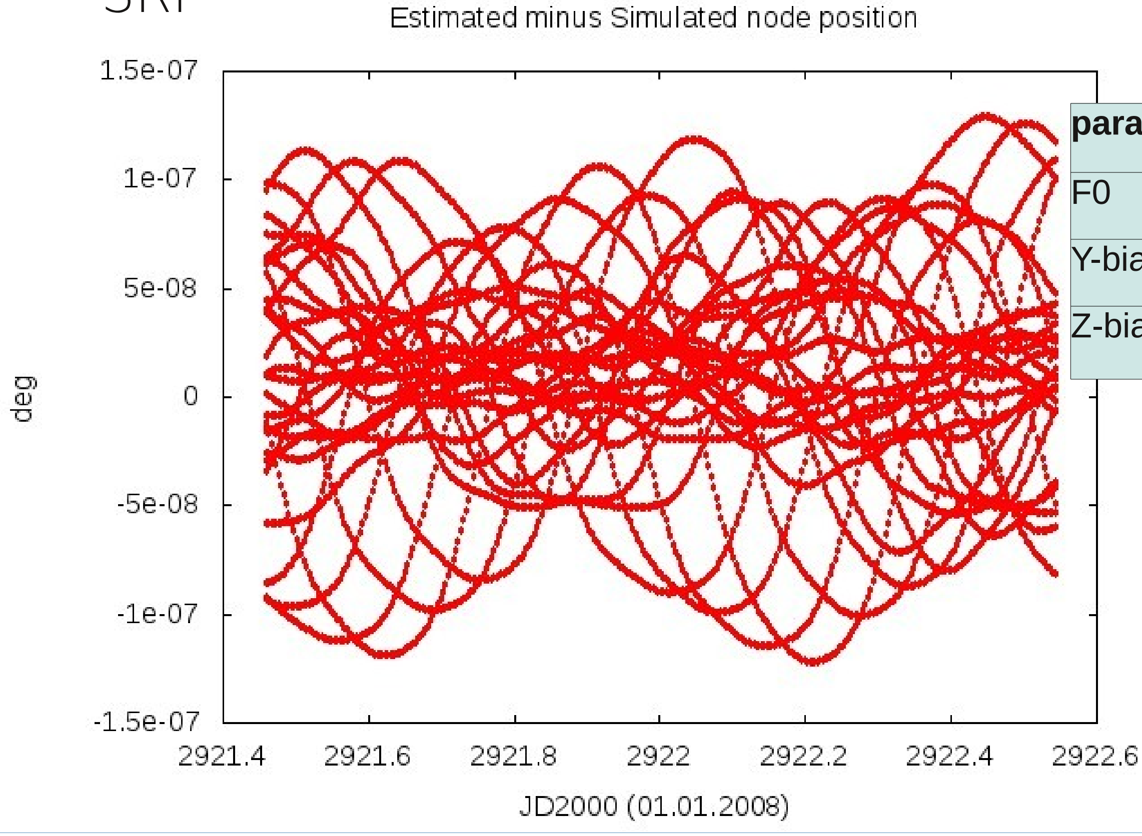
Error: Up to **1E-7 deg** (5 cm)

Two orders of magni-tude larger than the LT

It can be absorbed by the estimation of F0
=> estimate F0
Sigma = 10, 20%

4. Effects of the mismodelling in the SRP on the LT estimation

Error in the estimated node position due to a mismodelling in the SRP



parameter	value
F0	0.999 – 1.001 (total = 0.002)
Y-bias	-0.59600E-10
Z-bias	-0.13400E-07

Error: Up to **1.3E-7 deg**

=> Estimate Y, Z-bias

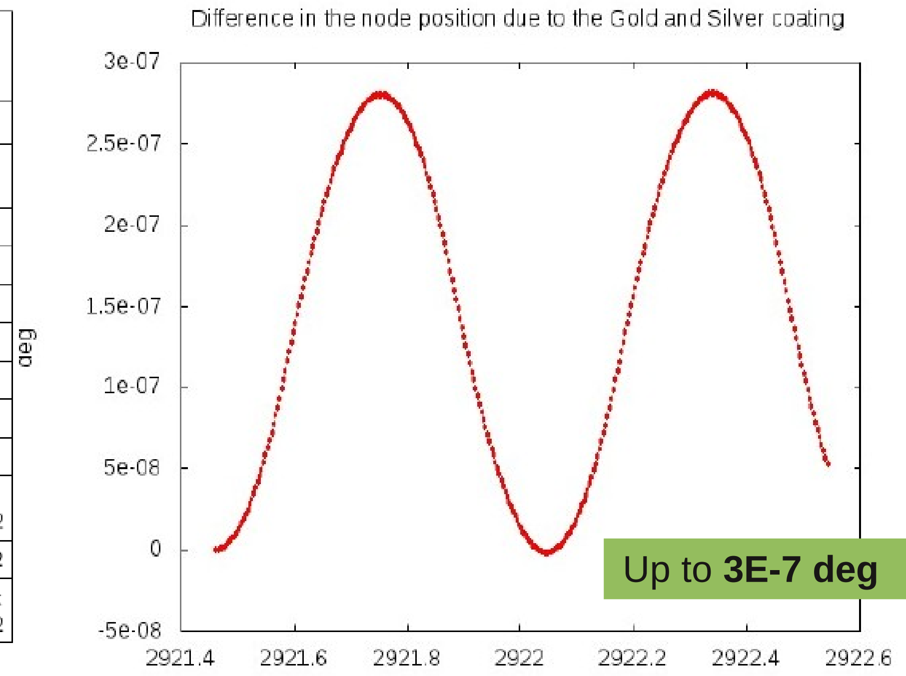
Consider a varying F0

4. Effects of the mismodelling in the SRP on the LT estimation

Macro models: displacement of the node due to different surface properties

Surface	Area (m2)	Normal vector in the satellite ref. system			Reflection coeff. for visible light				Reflection coeff. for infrared light		Relat. atomic mass	
					gold		silver/alum.					
		x	y	z	geometric	diffuse	geometric	diffuse	geometric	diffuse		
1	1.32	1			0.14	0.56	0.18	0.72	0	0.20	0	top
2	1.32	-1			0.14	0.56	0.18	0.72	0	0.20	0	bottom
3	2.75			1	0.14	0.56	0.18	0.72	0	0.20	0	left
4	2.75			-1	0.14	0.56	0.18	0.72	0	0.20	0	right
5	3.00		1		0.14	0.56	0.18	0.72	0	0.20	0	front
6	3.00		-1		0.14	0.56	0.18	0.72	0	0.20	0	back
7	11.70			1	0.04	0.16	0.04	0.16	0	0.20	0	Left S.P. SiO2
8	11.70			-1	0	0	0	0	0	0.20	0	left S.P. back MLI Kapt/SiO2
9	11.70			1	0.04	0.16	0.04	0.16	0	0.20	0	Right S.P. SiO2
10	11.70			-1	0	0	0	0	0	0.20	0	Right S.P. back MLI Kapt/SiO2

OHB, 2012



IMP => Galileo surface properties to model SRP, albedo

5. Conclusions

- Optimal parameterizations to estimate the LT effect from 1 and 3-days arcs have been obtained:

  (1) Optimal parameterization for 1-day arcs:

    - Either fix or constrain station coordinates with NNT-NNR-NNS conditions
    - Not to estimate normal components of the empirical forces

  (2) Optimal parameterization for 3-days arcs:

    - In addition to (1), do not estimate the Earth's albedo parameters (fix them)

- **These parameterizations allow to estimate LT with Galileo data**
- 3-days arcs are suitable to recover the LT effect from noisy data with this param. assuming that there are no errors in the rest of the models
- The estimation of phase ambiguities or a denser set of empirical coefficients does not influence the estimation of the LT effect

➡ Look for the optimal arc-length and parameterization with real Galileo data

5. Conclusions

- **The mismodelling of the SRP can hide the LT effect**
- **F0, Y and Z bias must be estimated**, they can not be fixed or highly constrained, since the error in the node due to the SRP reaches 2 orders of magnitude larger than the LT effect.
- The SRP parameter: **X-bias can not be estimated**
- Important to know the Galileo satellite characteristics: shape, size, weight, surface properties, attitude steering, maneuvers

- ➔ Use the macro models adapted to the Galileo characteristics along with an appropiate attitude model
- ➔ Analyse the effects of the errors in the background models on the estimation of the Galileo node position
- ➔ Run tests with real GPS and Galileo data

Thank you for your attention!

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