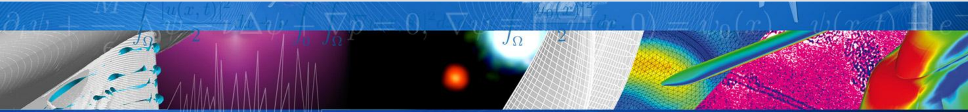

Measuring the Lense-Thirring effect with MICROSCOPE

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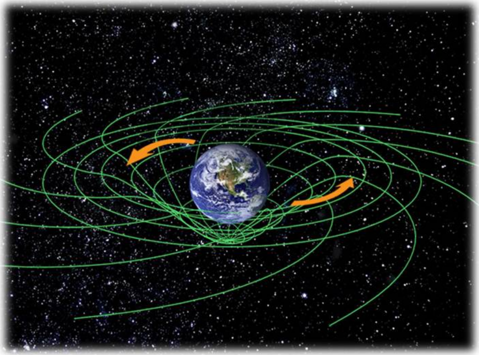
Overview

1. Principle
2. Proposed method
3. Error assessment
4. Conclusion

The Lense-Thirring effect

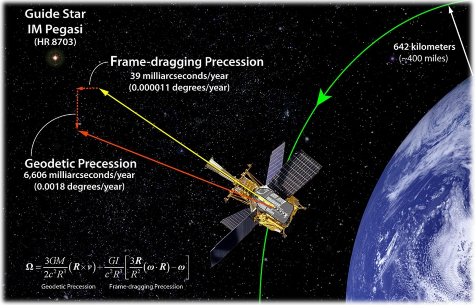
General Relativity predicts that the proper rotation of a central mass influences the dynamics of an orbiting body.



Source : Stanford University

The Lense-Thirring effect

Previous space-based experiments : Gravity Probe B and LAGEOS satellites



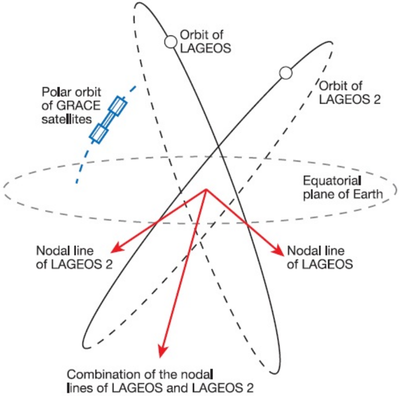
GPB

LAGEOS

image credits : NASA

The Lense-Thirring effect

LAGEOS measurement uses the motion of two point masses around the Earth.



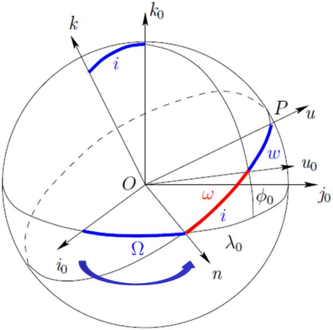
Ciufolini, 2004

Principle

- The argument of the node is shifting during the orbital motion

$$\frac{d\Omega}{dt} = \frac{4}{5}\frac{GM}{c^2}\frac{\omega_T R_T^2}{a^3(1-e^2)^{3/2}}$$

- For the MICROSCOPE orbit the node shift is about 2.4×10^{-14} rad/s $= 1\ \mu$rad/year



Source : Duriez, 2005

Possible ways of measurement

- direct measurement of the precession of the satellite orbital plane using orbit restitution: annual change of 6.5 m in the node position @ MICROSCOPE altitude.
- rotation measurements of the proof masses. Angular velocity precision specification : at best 10^{-9} rad s^{-1} $\Longrightarrow$ does not seem to be promising.
- use of the two accelerometers as a gradiometer to measure the Lense-Thirring contribution to the gravitational gradient. The LT potential contributes to the gradient at an order of magnitude of 10^{-10} of the Newtonian term. Contribution in the measured acceleration : 10^{-16} ms^{-2} at most, not likely to be achievable.

The orbit restitution seems to be the best tool to use

Measurement limitations

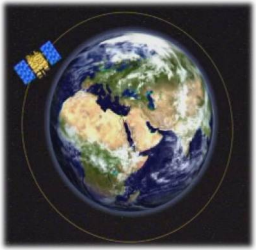
The main errors that can affect the measurement are :

- **Orbit restitution** (positioning)
- **Model errors** :
  - Terrestrial potential multipoles model
  - Drag free residuals

Orbit restitution

Orbit positioning challenges

1. Satellite motion undergoes several phases (the node shift during inertial session corresponds to 16 cm). So integration throughout the mission lifetime is not directly possible.
2. Performance of GPS receiver to be confirmed
3. Additional data analysis for orbit restitution will be necessary

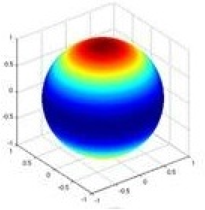


Model errors

Terrestrial potential multipoles

The even zonal coefficients of the Earth potential constitute the larger perturbation term in the node variation rate

$$\left(\frac{\Delta\Omega}{\Delta t}\right)_{J_{2p}} = -\sum_{p\geq 1} \frac{n}{\sin i}\left(\frac{R_e}{a}\right)^{2p} F'_{2p,0,p}(i)\delta J_{2p} \qquad (1)$$



J_2

$2p$	**Node shift**
2	3×10^{-15} rad s-1
4	3.5×10^{-15} rad s-1
6	2.4×10^{-15} rad s-1

Zonal coefficients contributions

Model errors

Drag free residuals

The non gravitational forces are measured and compensated by the drag free control loop $\implies$ no need to model them. The remaining contributor is the residual W_{res} that is normal to the orbital plane :

$$\left(\frac{d\Omega}{dt}\right)_{NG} = \frac{1}{na\sqrt{1-e^2}}\frac{r}{a}\frac{\sin(\omega+v)}{\sin(i)}W_{res} \tag{2}$$

Only the variations at orbital frequency have an impact.
The Science Mission Analysis (SMA) states that

$$W_{res} = 1 \times 10^{-13}\text{ms}^{-2} \text{ @ } f_{orb}$$

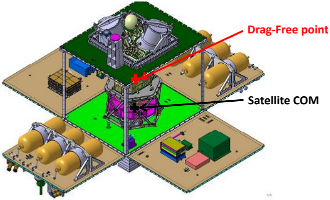
Equivalent shift : 7×10^{-18} rad.s^{-1} $\implies$ negligible

Model errors

Another aspect of gravitational residuals : the gravitational gradient between the satellite centre of mass (COM) and the drag-free point.

$$\vec{p} = -\overrightarrow{F_{nat}} - M_{sat}[T]\overrightarrow{G_{12}G}$$

G_{12} : drag free point
G : satellite COM
However the main component of the gradient peaks at $2f_{EP} \implies$ should not be a significant limitation



Summary

Error source	**Estimated contribution**
Orbit restitution	10 % ?
Earth Potential model	40 %
Drag free residuals	< 1 %

Error assessment summary

Conclusion

- We propose to carry out an analysis to observe the Lense-Thirring effect using the MICROSCOPE mission that is likely to be achievable with an error less than 100%
- Takes advantage of the drag compensation system
- This can be an independent and self-consistent measurement and can be improved by combining additional observables, for instance the LAGEOS satellites
- This is a way of validating DF performances (c.f. my PhD thesis)
- Further analysis must be performed to assess the expected performance

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Thank you