La costellazione Galileo e la fisica fondamentale

Measuring the galactic gravito-magnetism

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What's the problem?

Rotation curves of most galaxies (including ours) do not comply with Newton's gravity.

Option a) (most popular explanation): the Milky Way (and the other similar galaxies) is immersed in a huge, more or less spherical, dark matter halo (5-10 times more massive than the visible stars) whose gravitational attraction produces the observed rotation curve.

Conjecture and implication: the halo rotates together with the visible part of the MW $\rightarrow$ there's a gravitomagnetic field permeating the galaxy (including the solar system)

Option b) (consistent with Gaia's DR2 data)

Expressing from scratch the MW gravitational field in GR terms, it is possible to fit the data *without* having recourse to dark matter, but only relying on baryonic mass[1].

The line element within the galaxy is (cylindrical coordinates):

$$ds^2 = c^2 dt^2 - 2N(r,z)d\phi c dt - \left(r^2 - N^2\right)d\phi^2 - e^{\nu}\left(dr^2 + dz^2\right)$$

The role of GM is essential

[1]Mariateresa Crosta , Marco Giammaria, Mario G. Lattanzi and Eloisa Poggio. MNRAS **496,** 2107–2122 (2020).

How could we measure?

Sagnac-like technique: right/left asymmetry of the times of flight of light along a closed contour

$$\delta\tau = -\frac{2}{c}\sqrt{g_{00}}\oint \frac{g_{0i}}{g_{00}}dx^i \cong \frac{2}{c^2}B_{MW}S\cos\alpha$$

Extremely week signal expected: how to spot it?

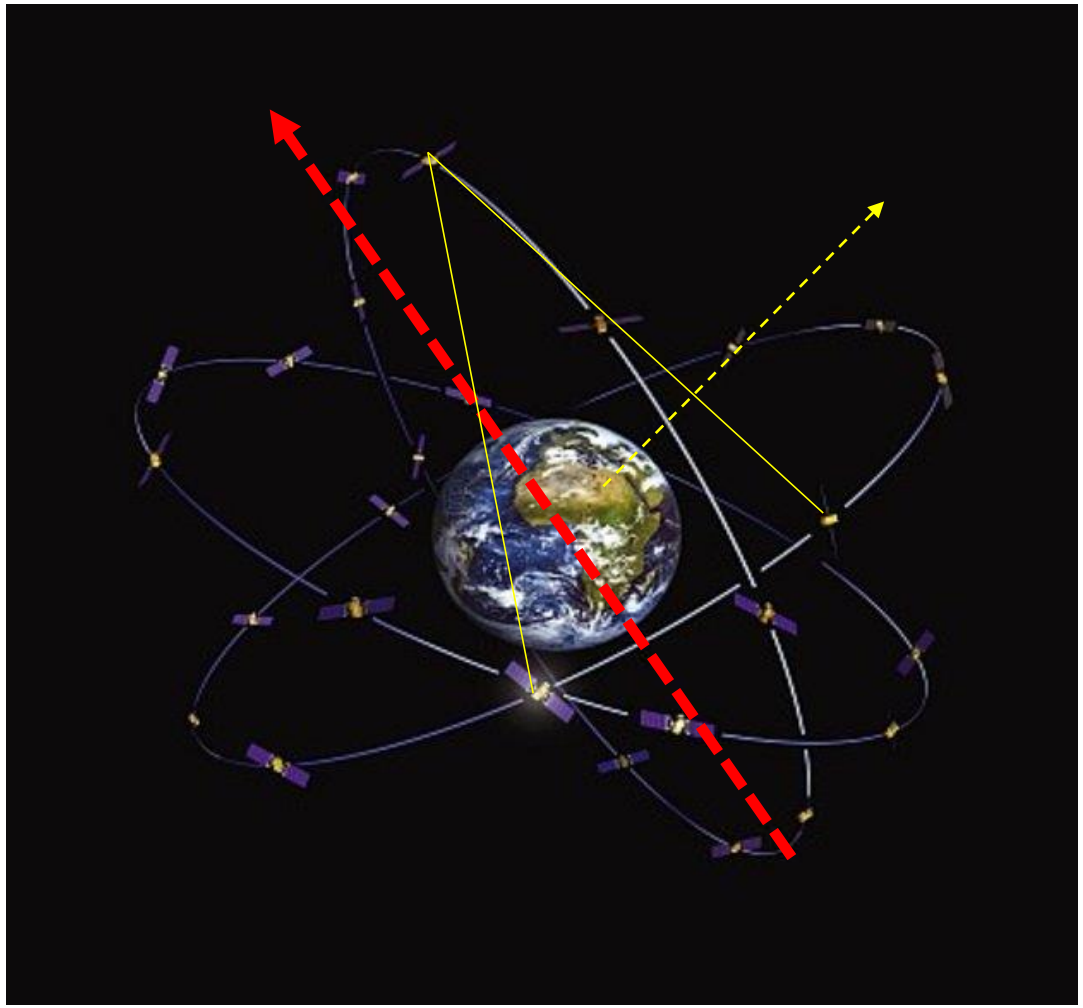
Time modulation of $S\cos\alpha$
«folding» over a long enough data taking

Galileo: the dance of the satellites

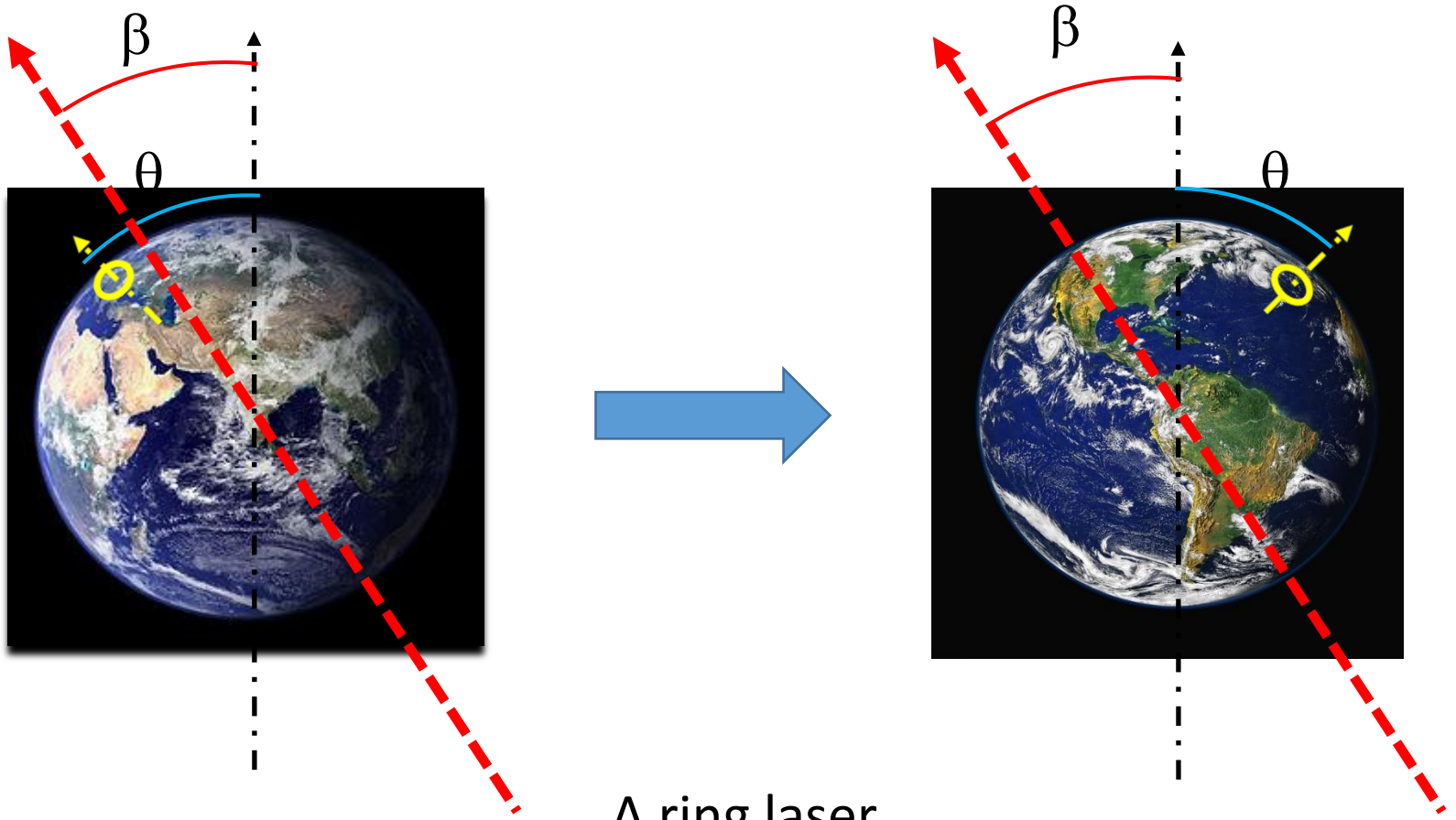
- Two satellites in one orbital plane
- One satellite on a different plane

The plane of the triangle oscillates with respect to the axis of the Milky way

14 hours modulation
$\delta t \sim 6 \times 10^{-18}$ s



Smaller scale: Measurements on earth? GINGER



A ring laser

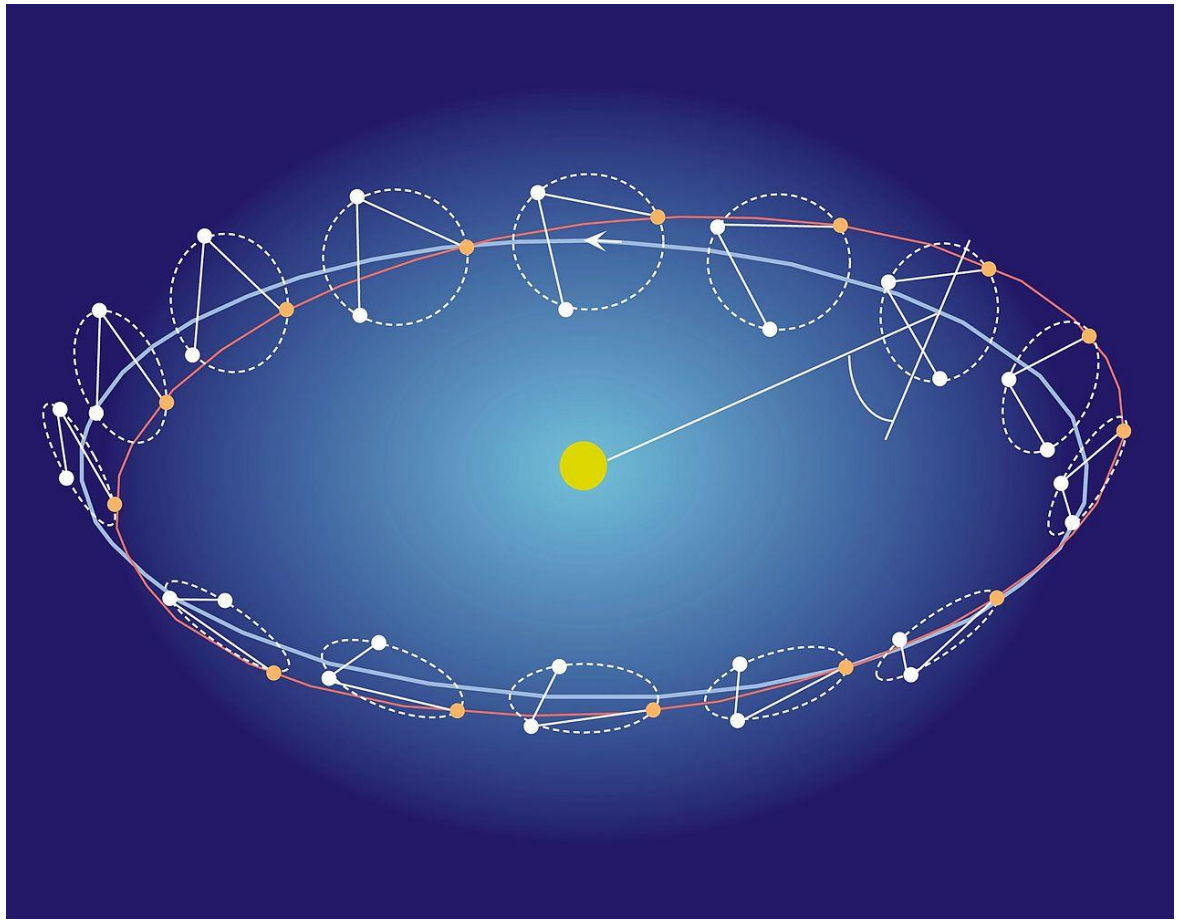
24 hours modulation

Bigger scale: the solar system
LISA

The use of the Sagnac effect is already foreseen[1]

Modulation: the Area Vector spans a cone with aperture 30^0 in one year

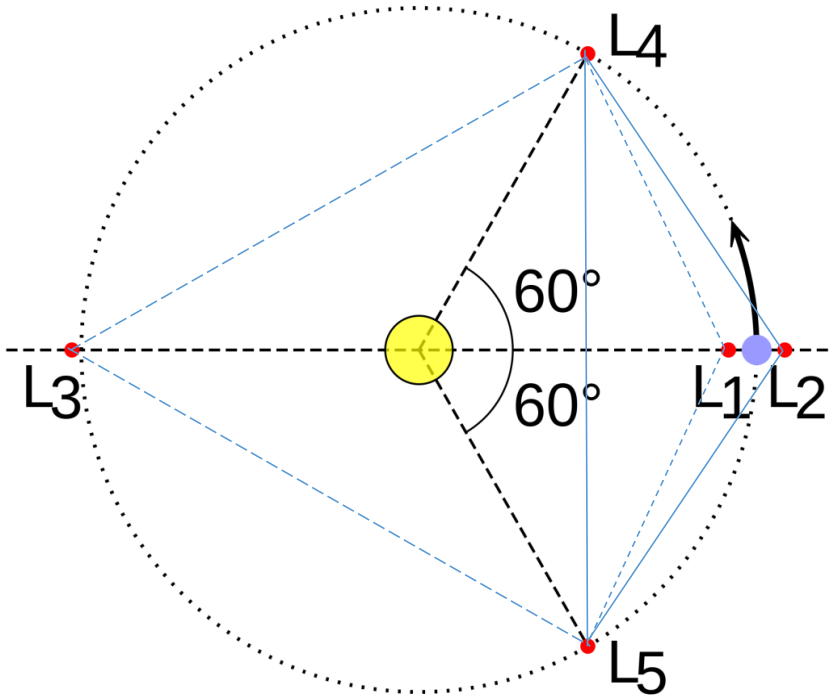
Multiplicative factor: $\sim 10^3$



[1]Daniel Shaddock, *Phys. Rev. D*, **69**, 022001 (2004)

Even bigger: **Lagrange**

Lagrangeian triangle L_2-L_4-L_5



Multiplicative factor: ~10^7

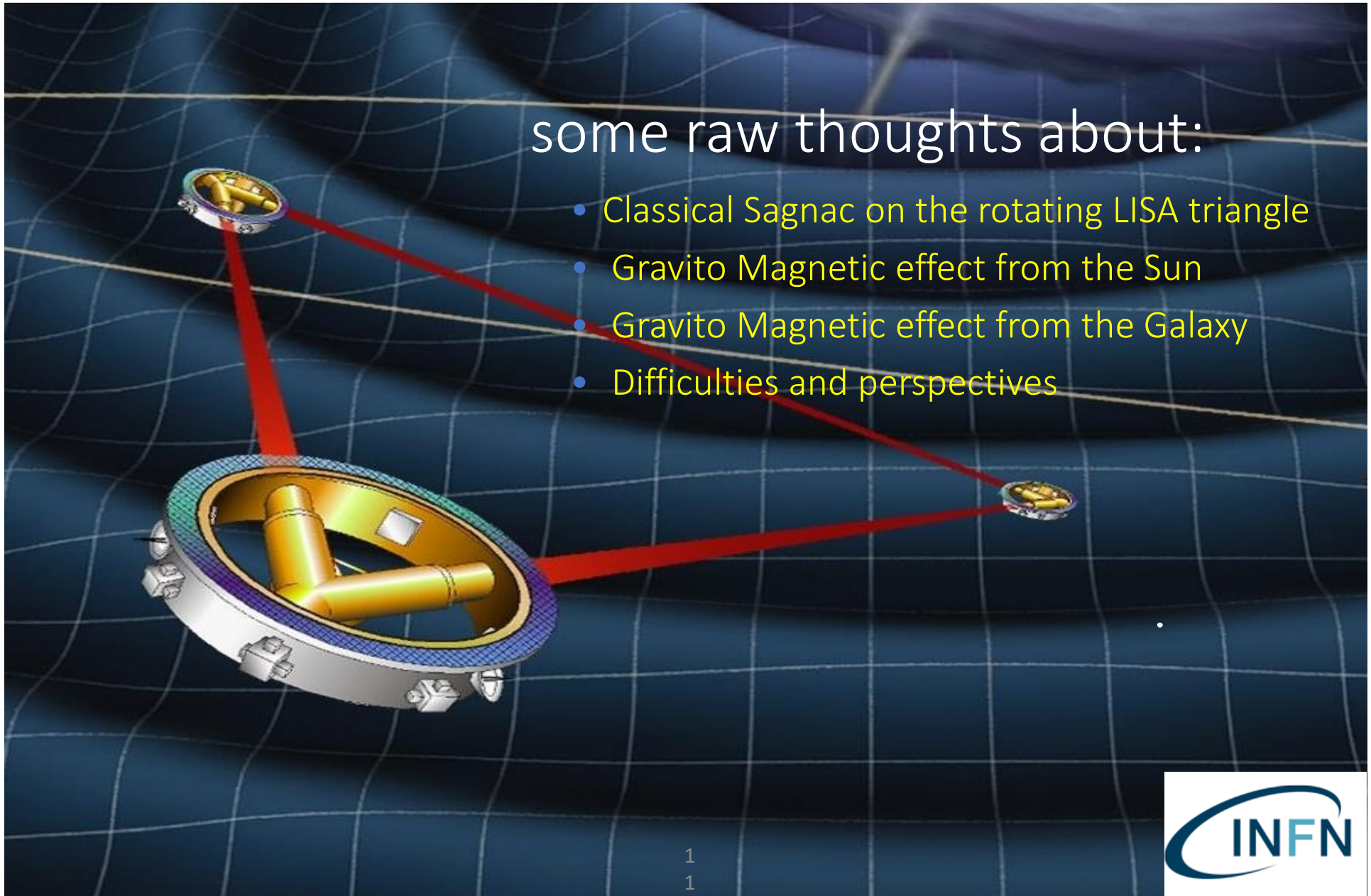
Angelo Tartaglia, *Advances in Space Research*, **64**, 545-550 (2019)

Vale la pena di provare

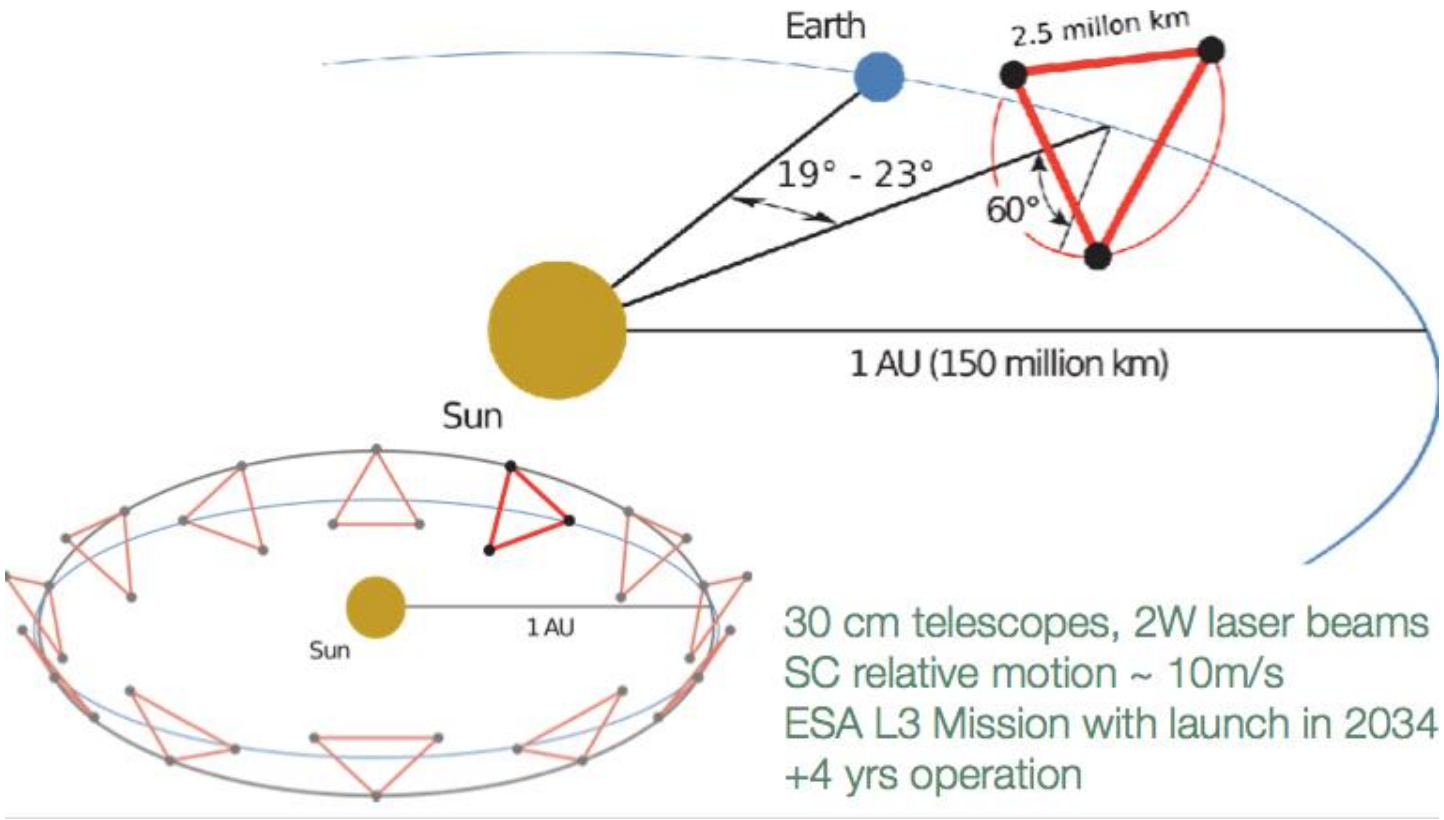
Approfondimenti su LISA

Cortesia di Massimo Bassan

Gravitomagnetism and LISA



LISA: Grav. Waves from space

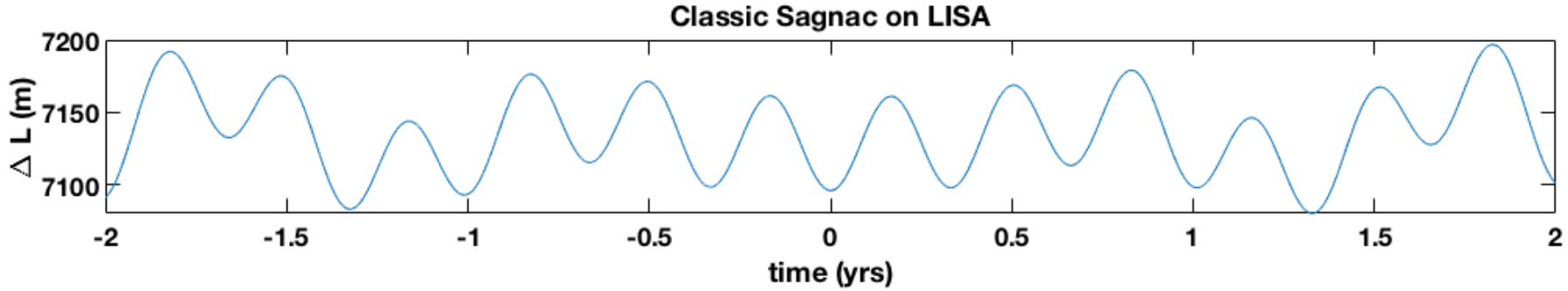


The Area Vector spans a cone with aperture 30^0 in one year

LISA: classical Sagnac Effect

$$\Delta\phi = \frac{8\pi}{\lambda c}\vec{A}\cdot\vec{\Omega}$$

$$\Omega = \frac{2\pi}{1\ year}$$

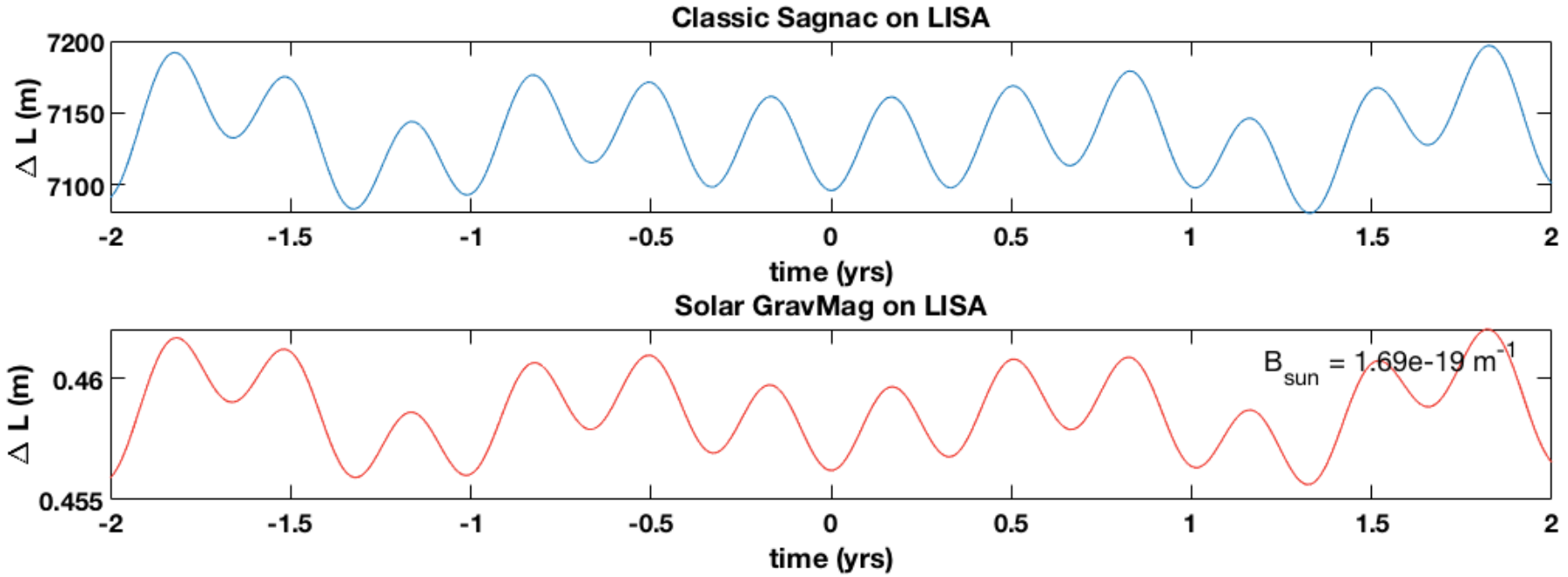


A large ΔL with small oscillations due to breathing and flexing of the constellation (Keplerian changes in size and angles)

$$\Delta L = 7200m \quad \Leftrightarrow \quad \Delta t = 24\mu s \quad \Leftrightarrow \quad \Delta\phi = 450\ 10^{-10} rad$$

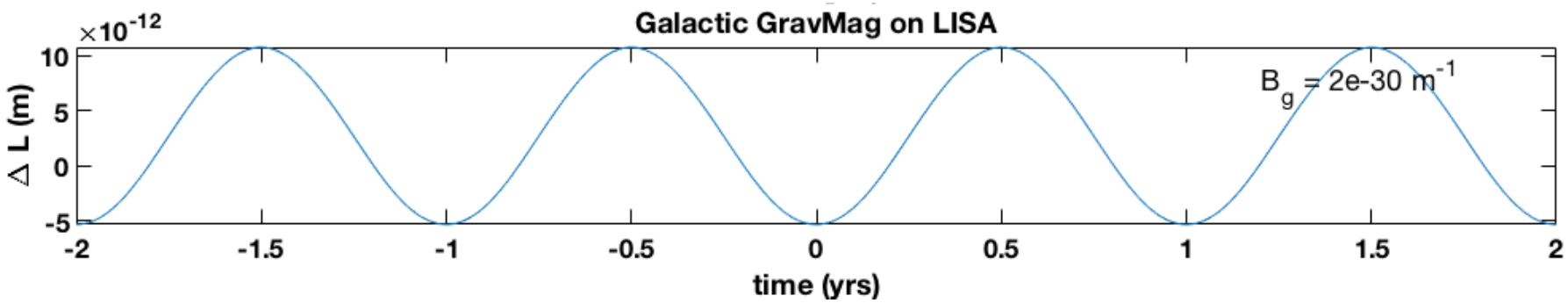
The area vector $\vec{A}$ spans a cone with aperture 30^0 in one year

GEM of Sun on LISA:



Same time behaviour (almost) but ~ 10^4 times smaller

GEM of Galaxy on LISA:

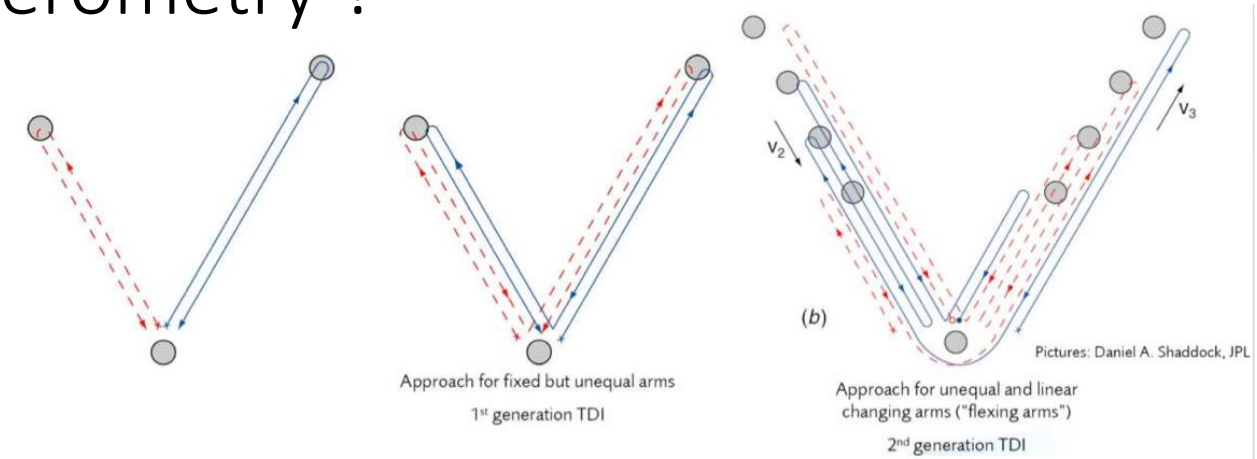


Full modulation (orientation wrt Galactic center changes) but:

- 1 year period like…everything !
- ΔL just below LISA sensitivity
- small statistics (10 cycles in mission lifetime)

A larger signal would be a signature of presence of co-rotating Dark Matter

Open question:
How does GEM signal emerge from Time Delay Inteferometry ?



$$X(t) = s_1(t) - s_2(t) - [s_1(t - 2\tau_2) - s_2(t - 2\tau_1)]$$
$$= [s_1(t) - s_1(t - 2\tau_2)] - [s_2(t) - s_2(t - 2\tau_1)]$$

$s_i(t) =$ laser phase in arm i
$\tau_i =$ one way light travel time down arm i

PHYSICAL REVIEW D **69**, 022001 (2004)

Operating LISA as a Sagnac interferometer

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pictures: D.A. Shaddock - JPL