GINGER

A terrestrial experiment

to verify the Lense-Thirring effect or possible deviations from General Relativity

Angelo Tartaglia

Small effects of General Relativity

Free fall

$$\frac{du^\alpha}{ds} + \Gamma^\alpha{}_{00}\left(u^0\right)^2 + 2\Gamma^\alpha{}_{0i}u^0u^i + \Gamma^\alpha{}_{ij}u^iu^j = 0$$

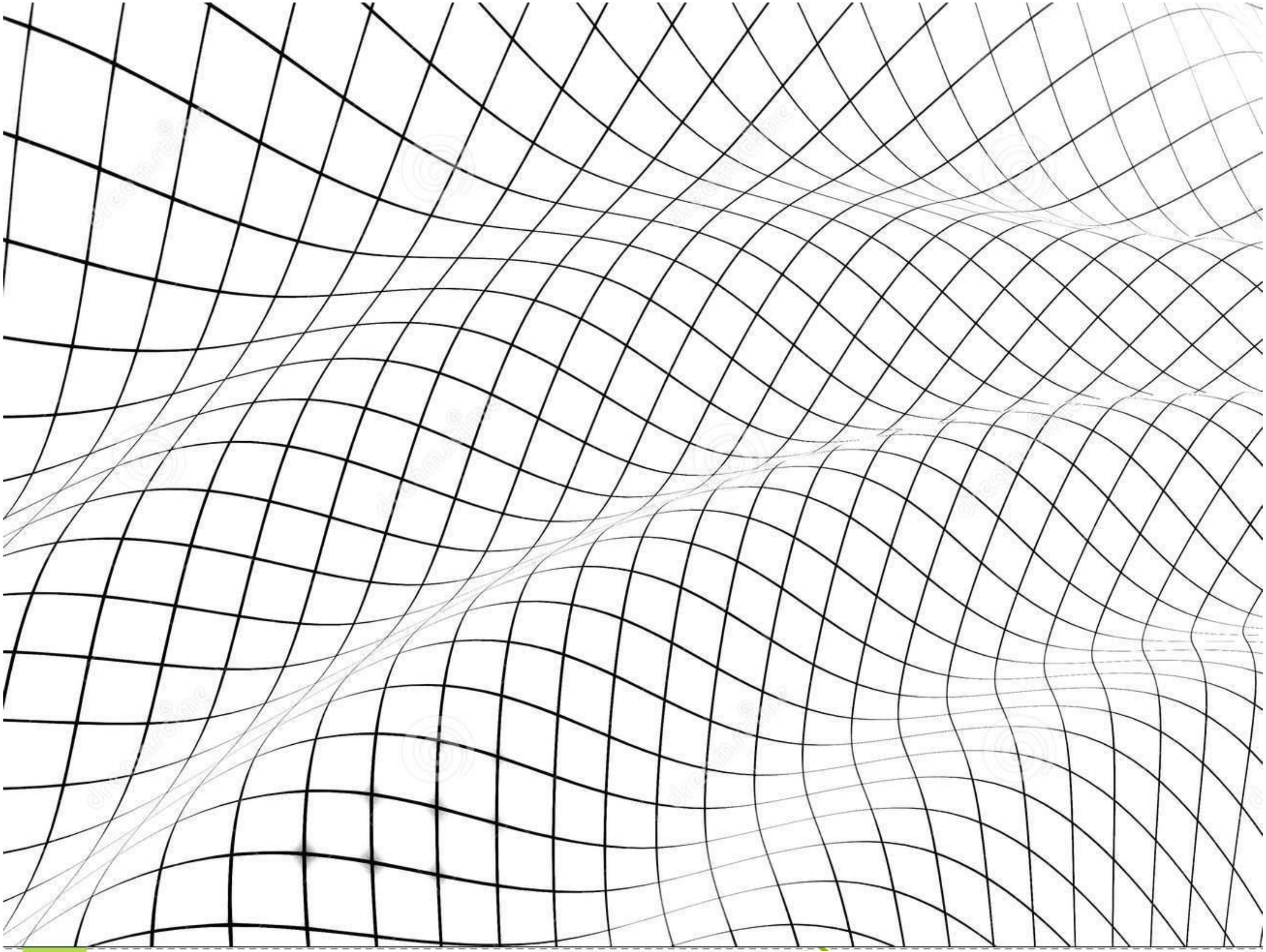
$$\Gamma^\alpha{}_{0i} = \frac{1}{2}g^{\alpha\beta}\left(\frac{\partial g_{0\beta}}{\partial x^i} + \frac{\partial g_{\beta i}}{\partial x^0} - \frac{\partial g_{0i}}{\partial x^\beta}\right)$$

Static metric

$$\Gamma^\alpha{}_{0i} = \frac{1}{2}g^{\alpha\beta}\left(\frac{\partial g_{0\beta}}{\partial x^i} - \frac{\partial g_{0i}}{\partial x^\beta}\right) = \frac{1}{2}g^{\alpha 0}\frac{\partial g_{00}}{\partial x^i} + \frac{1}{2}g^{\alpha j}\left(\frac{\partial g_{0j}}{\partial x^i} - \frac{\partial g_{0i}}{\partial x^j}\right)$$

$$\left(\Omega_{GM}\right)_k$$

Best covering of space-time by means of null geodesics



Chiral symmetry about a time axis

$$ds^2 = g_{00}c^2dt^2 + 2g_{0i}cdtdx^i + g_{ij}dx^idx^j$$

Light $\rightarrow ds = 0$

$$dt = \frac{-g_{0i}dx^i \pm \sqrt{\left(g_{0i}dx^i\right)^2 - g_{00}g_{ij}dx^idx^j}}{cg_{00}}$$

+

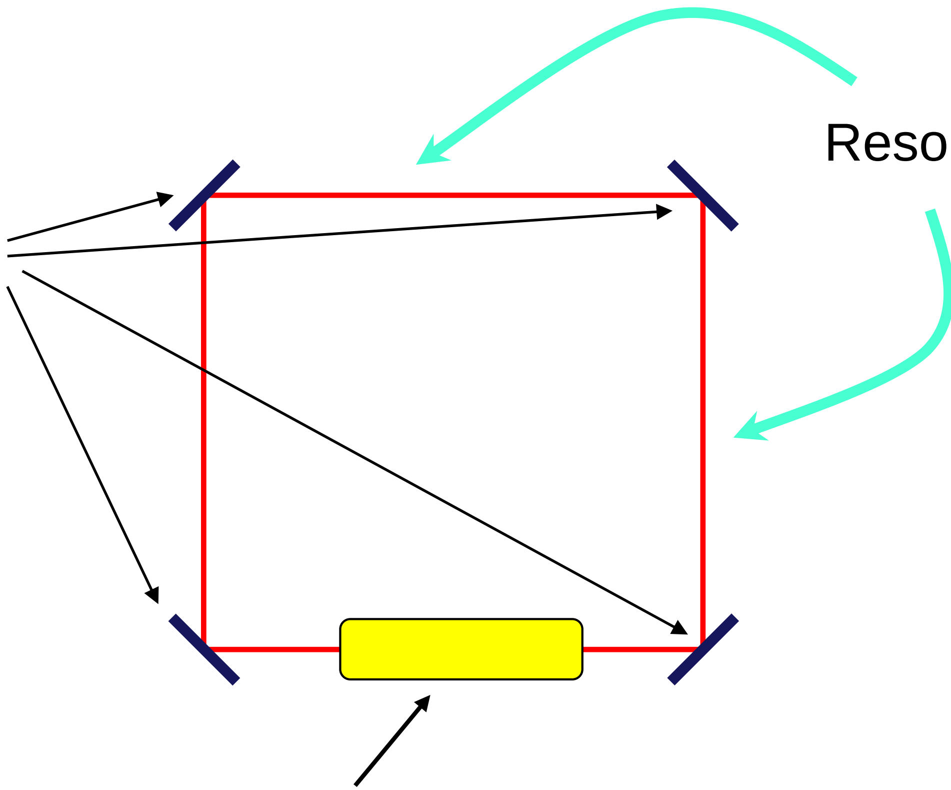
Closed path in space (proper length *L*)

$$x^i(\ell) = x^i(\ell + L)$$

$$dt = \frac{-g_{0i}\frac{dx^i}{d\ell}d\ell + \sqrt{\left(g_{0i}\frac{dx^i}{d\ell}\right)^2 - g_{00}g_{ij}\frac{dx^i}{d\ell}\frac{dx^j}{d\ell}}\,|d\ell|}{cg_{00}}$$

$$\Delta\tau = \tau_+ - \tau_- = -\frac{2}{c}\sqrt{g_{00}}\oint\frac{g_{0i}}{g_{00}}\frac{dx^i}{d\ell}d\ell$$

A ringlaser



Beat frequency

$$f_b = \frac{\Delta f}{2} = \frac{c^2}{2\lambda P}\Delta\tau$$

Length of the loop

Weak field (the earth), spherical space coordinates.

Expected signal

$$f_b = 2\frac{A}{\lambda P}\left[\vec{\Omega} - 2G\frac{M}{c^2 R}\Omega \sin\theta\,\hat{u}_\theta + \frac{GJ_\oplus}{c^2 R^3}\left(2\cos\theta\,\hat{u}_r + \sin\theta\,\hat{u}_\theta\right)\right]\cdot\hat{u}_n$$

Angular velocity of the device

Angular momentum of the earth

Scale factor

Area of the loop

Sagnac

$\vec{\Omega}_G$

$\vec{\Omega}_{LT}$

Mass of the earth

Bosi F., et al., *Phys. Rev. D*, vol. **84**, p. 122002/1-23 (2011)

Ringlasers at rest on the rotating earth

Ω coincides with $\Omega_{\otimes}$

GR terms ~ $10^{-9} \times$ the kinematical contribution (Sagnac term)

de Sitter (geodetic) term: almost same order as the Lense-Thirring term

$$\Omega = 7.2 \times 10^{-5}\, s^{-1}$$

$$\Omega_G \approx 10^{-10}\, \Omega$$

$$\Omega_{LT} \approx 10^{-9}\, \Omega$$

Metric theories other than GR

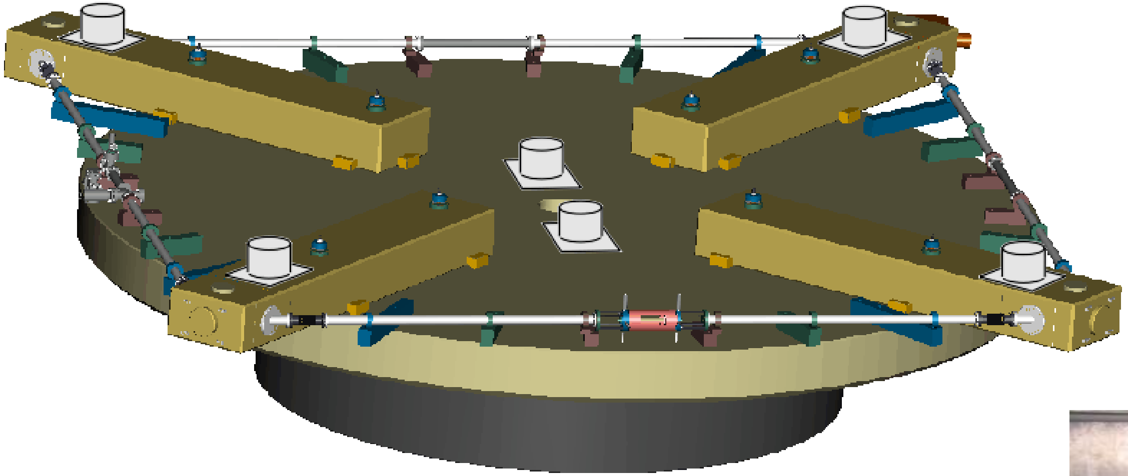
In the expected results two *ppN* parameters appear: γ and α_1

$$\Omega_G = -\left[2+(\gamma-1)\right] G \frac{M}{c^2 R} \Omega \sin\theta \, \hat{u}_\theta \cdot \hat{u}_n$$

$$\Omega_{LT} = \frac{2+(\gamma-1)+\alpha_1/4}{2} G \frac{J}{c^2 R^3} \left(2\cos\theta \, \hat{u}_r + \sin\theta \, \hat{u}_\theta\right) \cdot \hat{u}_n$$

GR: $\gamma = 1$ $\alpha_1 = 0$

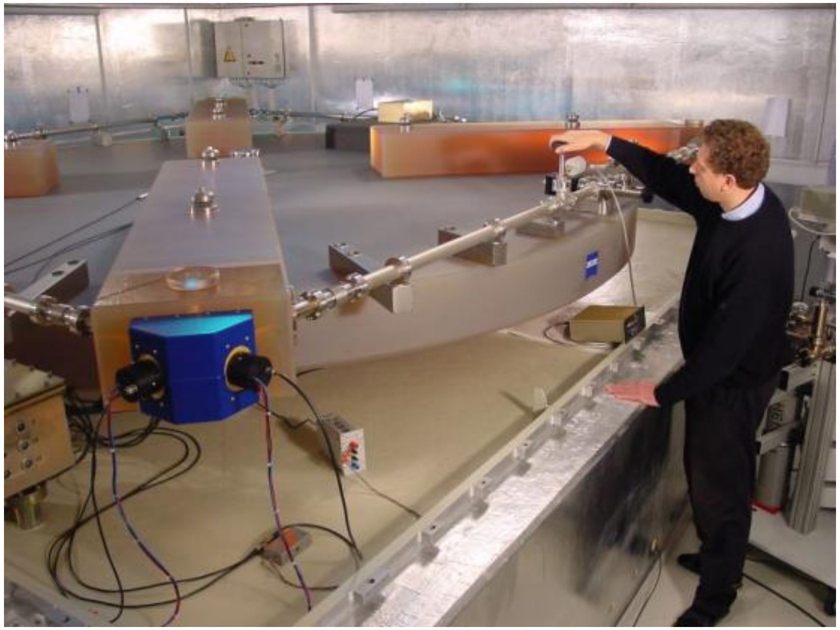
G instrument at the Geodätisches Observatorium Wettzell



Absolute sensitivity:

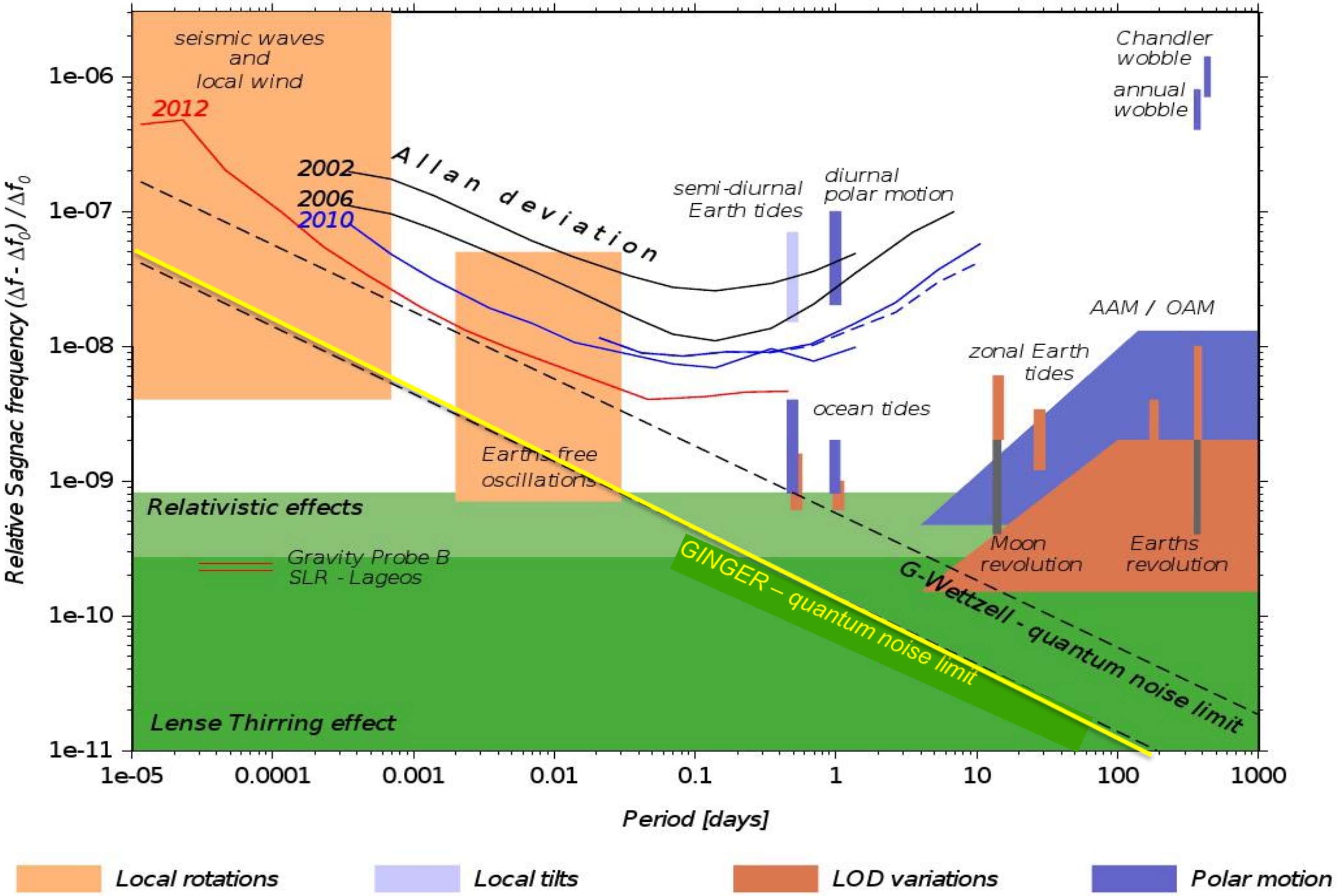
~ 10^{-12} rad/s/√Hz

Side: 4 m
Power: 20nW
Zerodur support

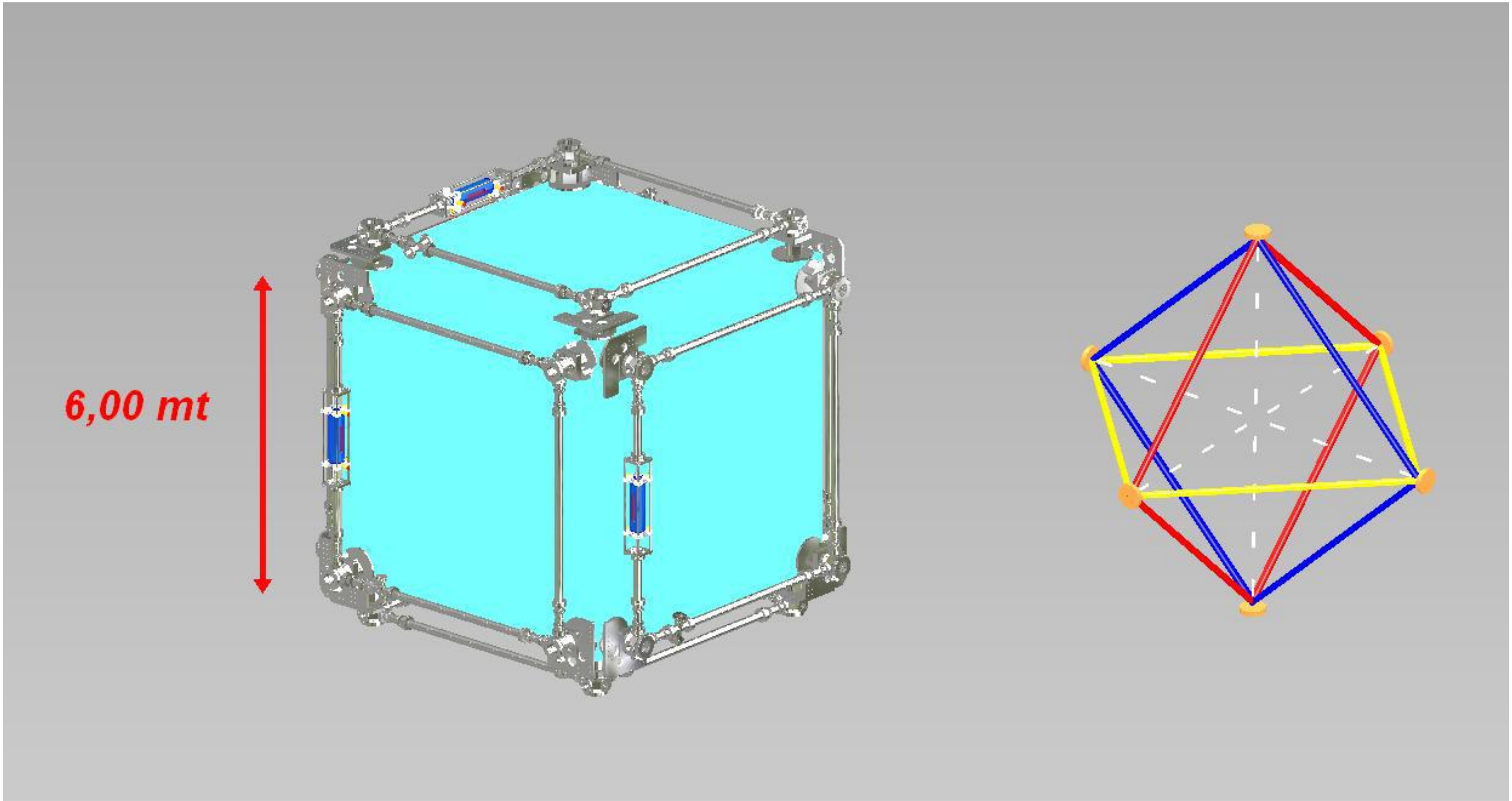


GINGER: proposed and under development

- Three-dimensional ring lasers array (three to six or more)
- Laser power: ~ 200 nW
- Quality factor of the cavity: Q $\geq 3\times10^{12}$
- Square loop, $\geq$6 m in side
- Underground location (LNGS)
- Purpose: to measure the LT effect with a 1% accuracy (one year integration time)


seismic waves
and
local wind
2012
2002
2006
2010
Allan deviation
semi-diurnal
Earth tides
diurnal
polar motion
Chandler
wobble
annual
wobble
AAM / OAM
zonal Earth
tides
ocean tides
Earths free
oscillations
Relativistic effects
Gravity Probe B
SLR - Lageos
Moon
revolution
Earths
revolution
GINGER – quantum noise limit
G-Wettzell - quantum noise limit
Lense Thirring effect
Relative Sagnac frequency (Δf - Δf0) / Δf0
1e-06
1e-07
1e-08
1e-09
1e-10
1e-11
1e-05
0.0001
0.001
0.01
0.1
1
10
100
1000
Period [days]
Local rotations
Local tilts
LOD variations
Polar motion

Configurations



GINGERino (assembled 2014, now working at LNGS)

3.6 m side

Piezoelecric control of the perimeter

Collaboration

P.I. Angela Di Virgilio	Pisa-INFN
J. Belfi, N. Beverini, F. Bosi, B. Bouhadef, G. Carelli, G. Cella, E. Maccioni, R. Santagata, A. Simonelli, G. Terreni	Pisa-University and INFN
A. Beghi, D. Cuccato, G. Naletto and A. Ortolan	Padua-University and Legnaro INFN Labs
C. Altucci, G. Passeggio, A. Porzio R. Velotta	Naples-CNR and INFN
M.L. Ruggiero and A. Tartaglia	Turin-Politecnico and INFN
C. Zarra	Assergi-LNGS
Ulrich Schreiber	Technische Universität München
Jon-Paul Wells	University of Canterbury, Christchurch, New Zealand

References

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- N. Beverini, et al., *Laser Phys.*, vol. **74**, 074005 (2014)
- M.L. Ruggiero and A. Tartaglia, *Eur. Phis. J. Plus*, vol. **129**, 126 (2014)
- F. Bosi, et al., *Phys. Rev. D*, vol. **84**, 122002/1-23 (2011)

Remind

ppN parameters

- γ : space curvature per unit mass
- α_1: local drag anisotropy