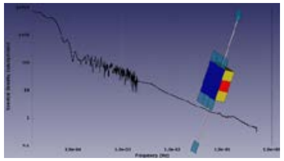

LIG-A-CubeSat (Laser Interferometry Gauge Accelerometer on CubeSat): Demonstration of novel high sensitive accelerometer for science and technology

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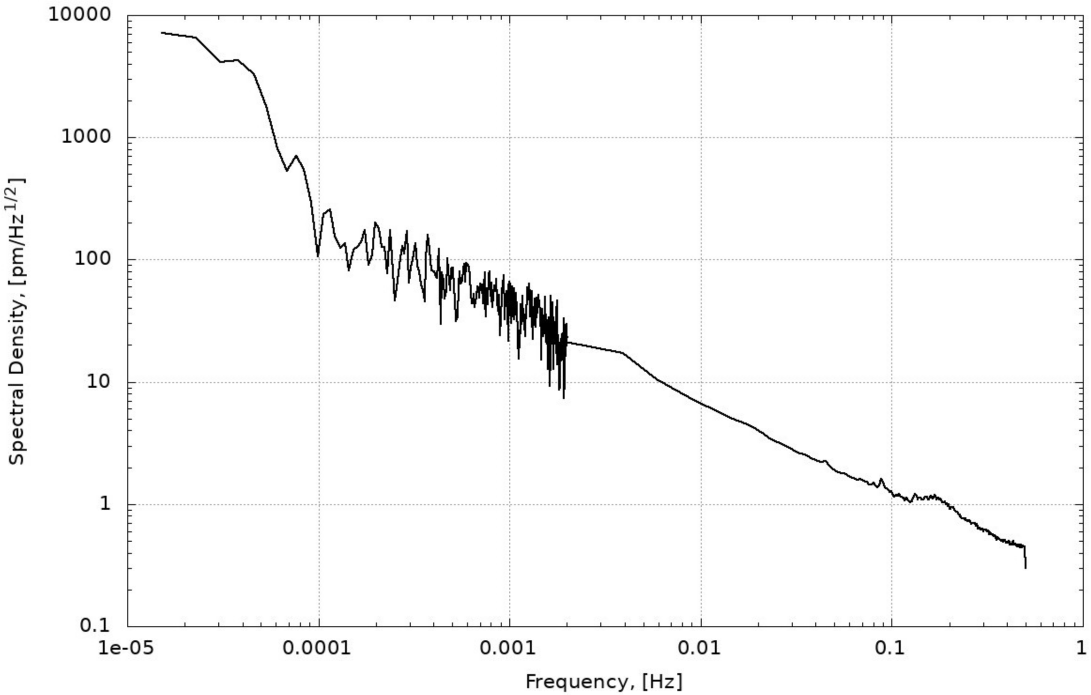
Motivation and lab performance of LIG (Laser Interferometry Gauge)

-Measuring accelerations onboard s/c around Earth, other planets or cruise phase is needed for science (measure gravitational potential, assess non gravitational forces, radio science and precision experiments) and technology (assess performance of thrusters, drag-free control)

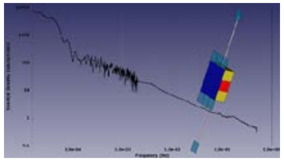
-High sensitivity is required at low frequencies

-Accelerometer needs: “almost” free TM (Test Mass) inside s/c & readout of its displacements relative to s/c

LIG readout optical components: to be miniaturized as “LIG-on-a-chip”



LIG noise (low frequency increase likely due to lab noise)



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LIG vs state of the art laser interferometry and capacitance readout

-LIG noise comparable to LPF (LISA pathfinder) laser Interferometer on ground (increases at low frequencies too…)

Class. Quantum Grav. **28** (2011) 094002 F Antonucci *et al*

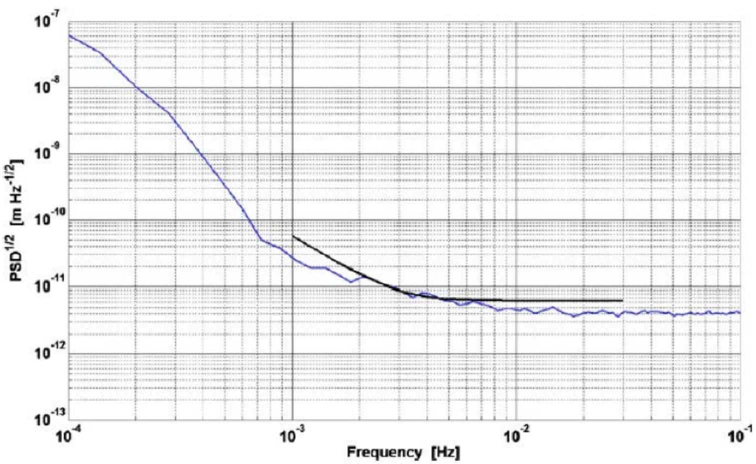


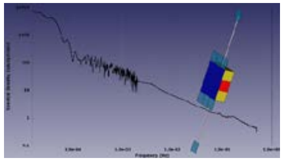
Figure 2. Square root of the PSD of the output of the x_{12} interferometer within the flight model of the entire chain of the optical metrology. Only the optical bench is replaced by an engineering model. Noisy long line: experimental data. Shorter smooth line: requirements. The increase below about 0.7 mHz is attributed to the laboratory environment.

-LPF accelerometer in space (TM suspended, read and controlled by capacitors): capacitance readout at nanometer (not picometer) level; it would improve with submillimeter gaps, but other noise sources appear…

PHYSICAL REVIEW D 96, 062004 (2017) LISA Pathfinder Collaboration

Capacitive sensing of test mass motion with nanometer precision over millimeter-wide sensing gaps for space-borne gravitational reference sensors

-THE IDEA BEHIND LIG-A ACCELEROMETER
If laser interferometer reads a test mass suspended mechanically (suspension very weak in absence of weight, test mass sensitive to very tiny accelerations!!) TM is stable (launch lock and release in orbit no issue), no capacitors & no active electric discharger needed, no gap limitation AND laser readout much better than capacitive readout.
Successfully tested in the lab using ISA (Italian Spring Accelerometer; GGG version, similar to ISA flying on BepiColombo).
Next: full performance demonstration in orbit with CubeSat (much higher test mass sensitivity & much lower noise than on ground)



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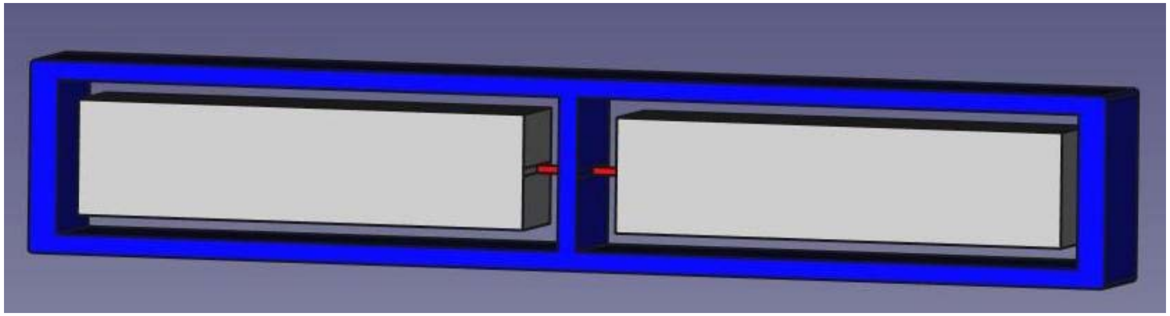
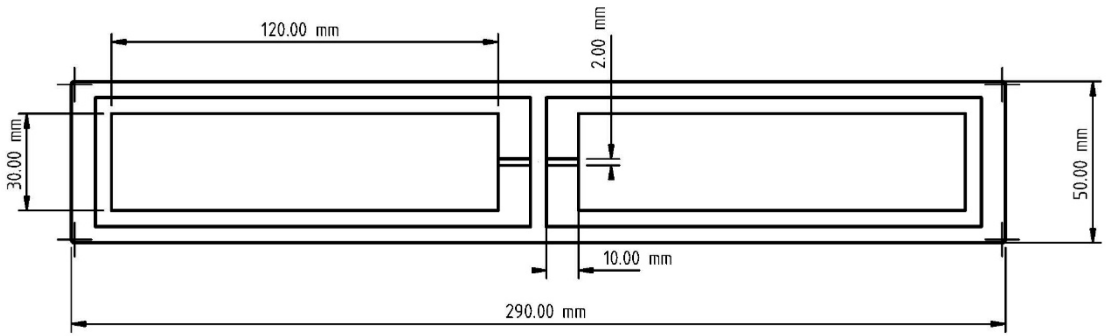
TM design & performance



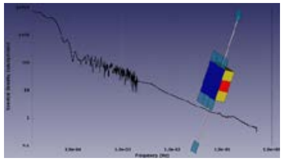


“Butterfly” configuration of the test masses (first used for ISA accelerometers, in which the TM shape was optimized for cap sensing)

Frame rigid with s/c (blue), TM (grey), suspension lamella (red):
sensitive to accelerations perpendicular to each TM face (common mode and differential mode) + rotations around mid axis of frame.
Complete with 2 LIG interferometers is the science payload and fits in 3U

-Below its natural frequency of 0.07Hz each TM is sensitive to very small accelerations:
at 1mHz LIG readout noise of 30 pm/√Hz yields 6×10^{-12} ms^{-2}/ √ Hz acceleration noise.

-Can a low cost CubeSat mission in low Earth orbit, no drag-free control, passive attitude stabilization & very tight mass and power budget be designed such that the s/c is so “quiet” (low noise) to demonstrate this challenging performance?



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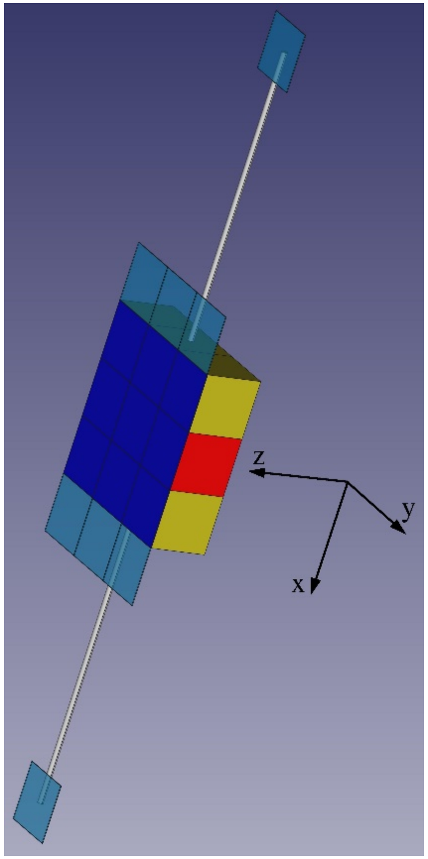
LIGA-A-CubeSat: The orbit, the spacecraft and the mission



- 500km altitude; sun synchronous dawn/dusk orbit; non zero eccentricity acceptable
- s/c attitude Earth pointing, passively stabilized by gravity gradient (2 booms deployed along radial direction)

x to CM of Earth
y transversal (xy orbit plane)
z perpendicular to orbit plane (roughly to the Sun)

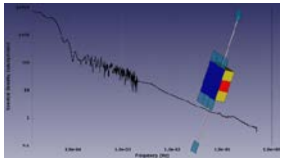
9U Cubesat ; 17 solar panels (10 x 10 cm^2 each) , 8 of them deployed

Total mass: 12.5 kg (including 4.5 kg payload)
Total power available: 62.64 W (40.6 W required by payload; reduction to 26.6 W under investigation)

Vega Launch
Standard omnidirectional antenna & telecommunication system
Standard Command & Data System
Standard power system
Passive thermal stabilization
GPS for orbital positioning
Star tracker for attitude determination
Boom deploy system
Passive TM launch lock (as in BepiColombo)
No thrusters, no drag-free control, no attitude control (passive magnetic dampers only if needed)
1 to 2 months mission duration (see next slide)

How quiet is the s/c?

Non gravitational forces:
-Solar radiation pressure: $\approx 6\times10^{-8}$ ms^{-2} (mostly along z)
-Atmospheric drag: $\approx 2\times10^{-8}$ ms^{-2} (mostly along y)
-Drag due to air dragging by Earth's rotation: about 10 times smaller than drag, directed along z, changes sign every half orbit causing small satellite oscillations around x (can be damped by passive magnetic dampers if necessary)
Main effects of drag are long term (very low frequency), at orbital frequency (υ_{orb} =1.75x10^{-4} Hz) and at twice it ($2\upsilon_{orb}$ = 3.5x10^{-4} Hz) due to Earth's oblateness (3x10^{-3}) and consequent variation of air density with altitude



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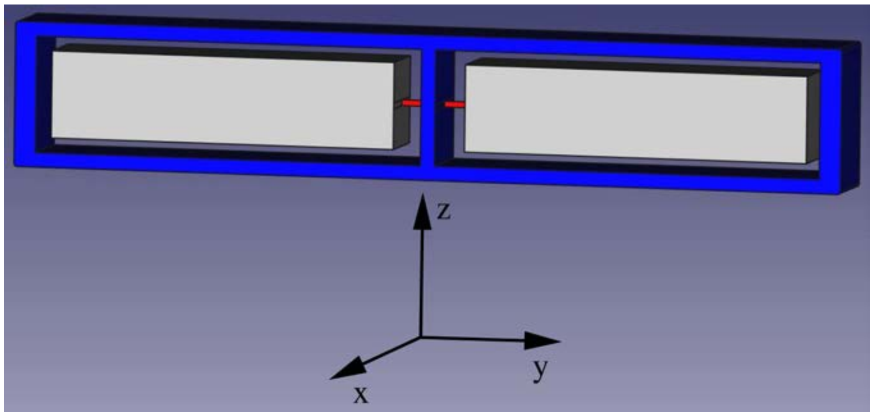
The LIG-A on CubeSat experiment and the mission goal

-Each TM sensitive to linear accelerations along x (radial direction); differences smaller by a factor 100 (Common Mode Rejection by construction)

- "Butterfly" sensitive to rotations around z axis Axes choice: once in orbit it is the least affected by non gravitational forces.



Earth tidal (gravity gradient) acceleration on each TM linear with orbital eccentricity and radial separation from CM of the s/c.
Acts on each TM along x at orbital frequency (1.75×10^{-4}Hz); has the same sign (no rotation around y); is deterministic (unlike non gravitational effects)

With $e = 0.01$ and 2 cm radial separation: $a_{tide} \approx 7.2 \times 10^{-10}$ ms^{-2} , and a residual of 7.2×10^{-12} ms^{-2} after common mode rejection.
With 200pm/√Hz displacement noise demonstrated in the lab at 1.75×10^{-4}Hz TM acceleration noise is 3.8×10^{-11} ms^{-2}/√Hz, yielding 5×10^{-13} ms^{-2} in 1 orbital period integration time.

Drag accelerations at υ_{orb} and $2\upsilon_{orb}$ can also be detected with a few days integration time.
Low frequency noise due to long term drag effects is expected to decrease as the square root of the integration time and suggests a 1 to 2 months mission duration to ensure reaching at 0.1 mHz level the mission goal of an acceleration noise of 6×10^{-12} ms^{-2}/√Hz below 0.07 Hz, at mHz range.

The known signature of the tidal effect, with reasonable GPS orbit determination, will allow the accelerometer to measure a known physical signal in addition to demonstrating an outstanding low level of acceleration noise.

A conservative estimate of the effect of rotations around z axis (due to non gravitational forces) shows rotation angles at arcsec level and TM linear displacements of a few hundred nanometer.
They can very well be measured and no problems of dynamic range arise. Together with the star tracker attitude determination they will allow non gravitational effects to be better separated from the tidal signal to be recovered.