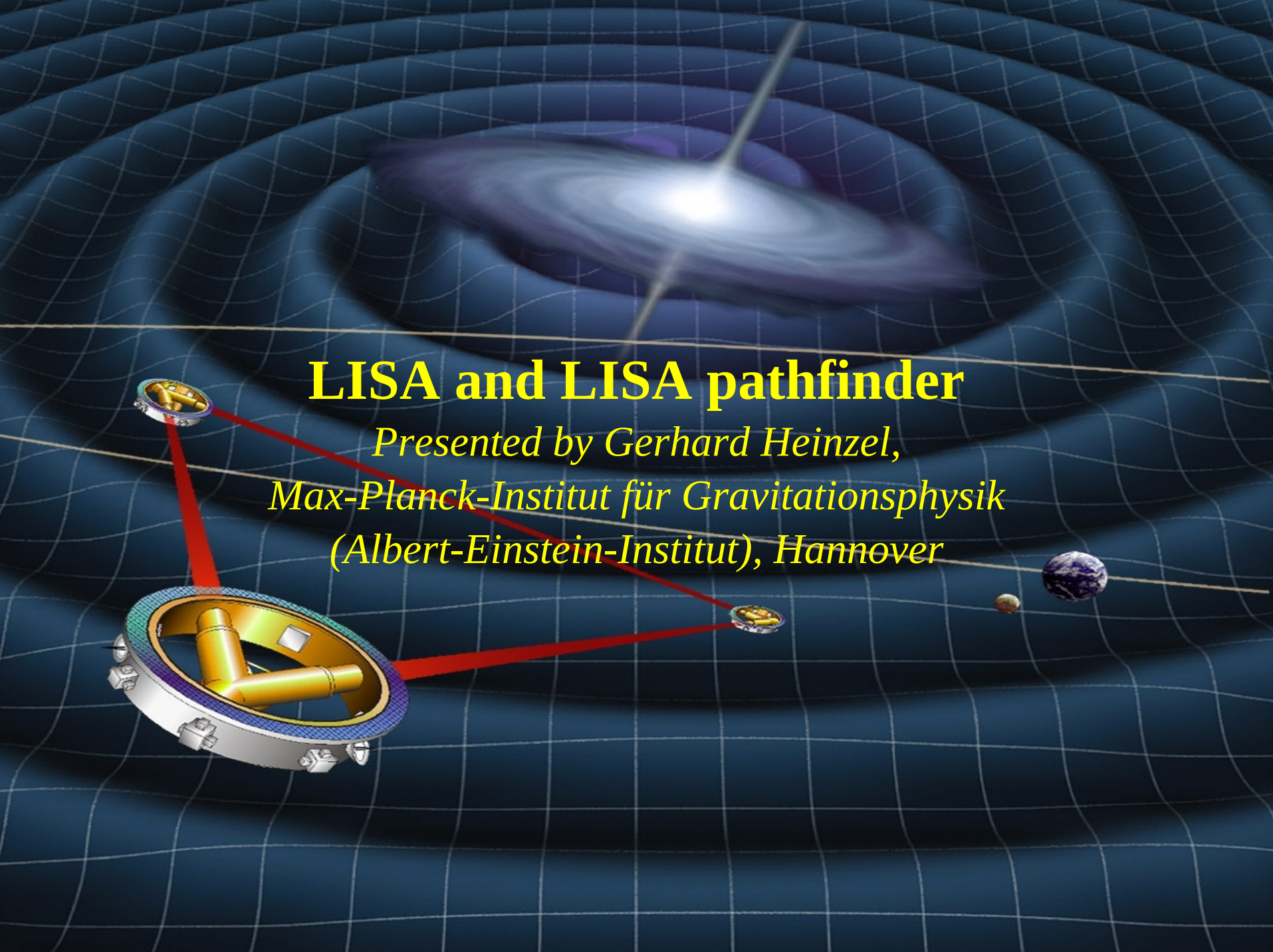
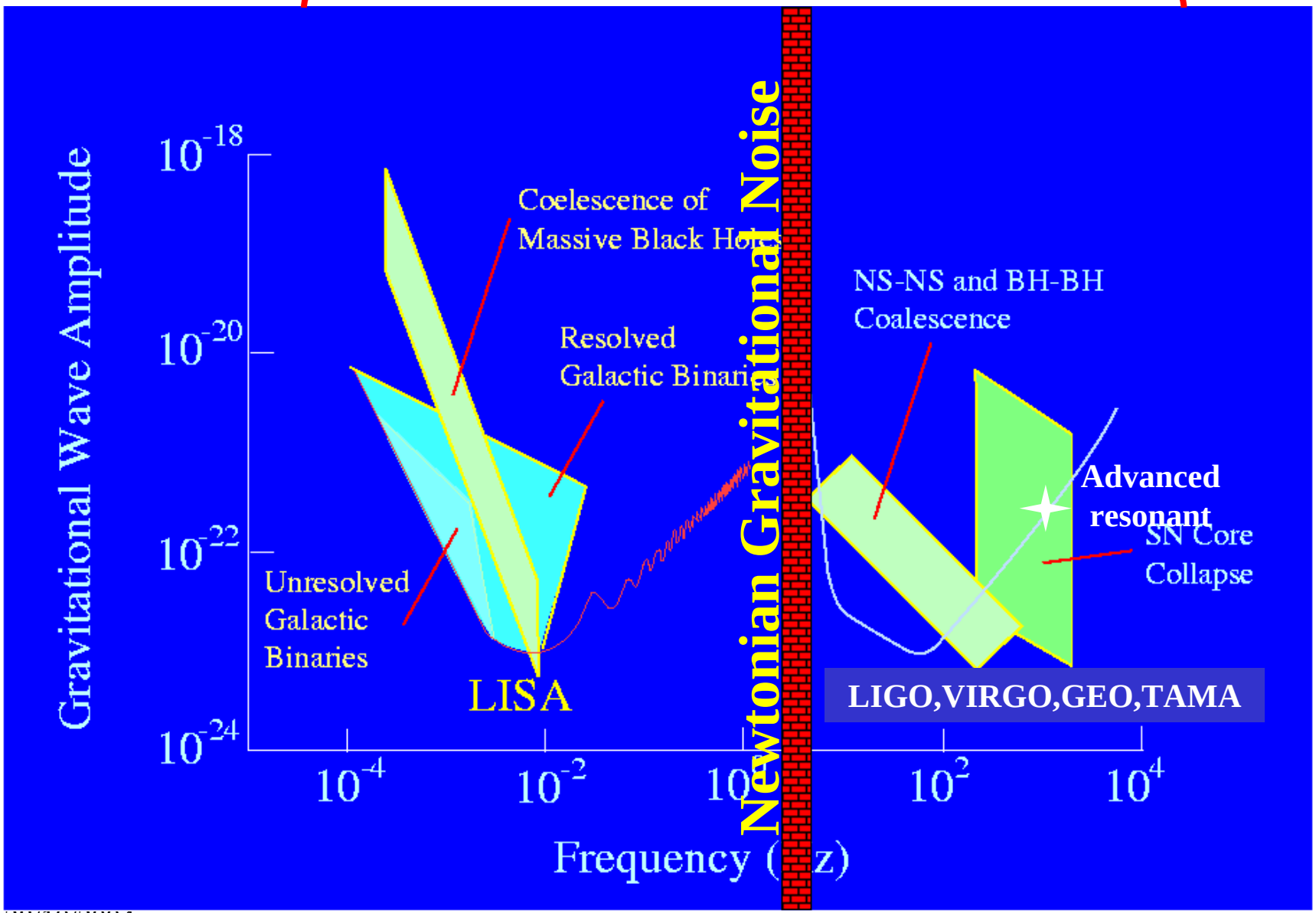


LISA and LISA pathfinder

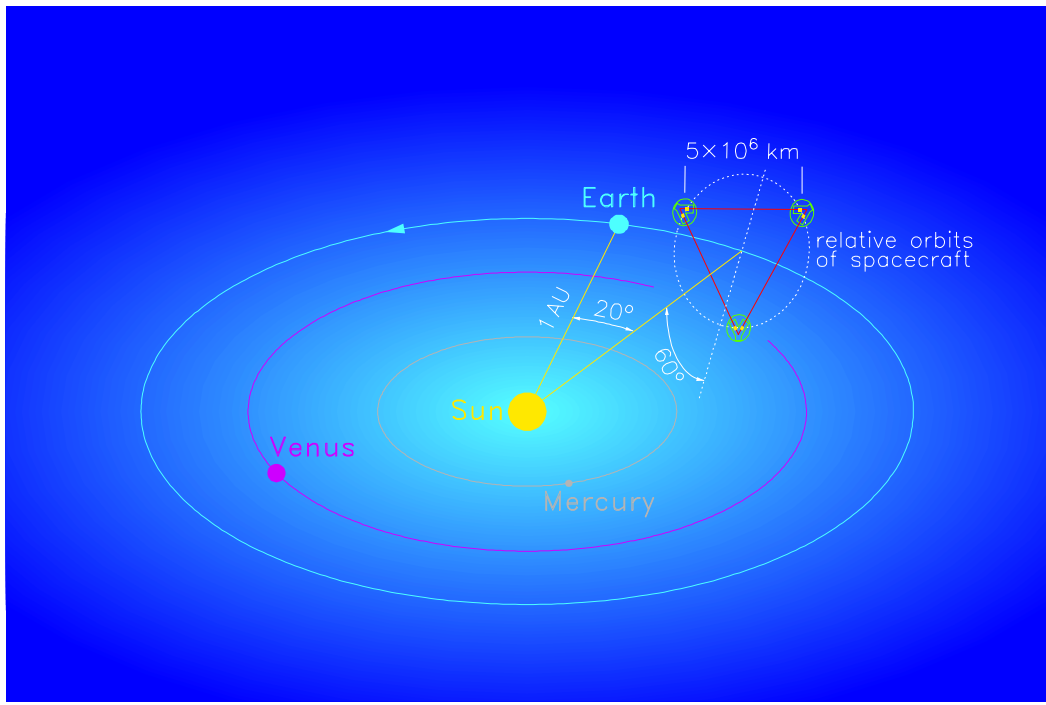
Presented by Gerhard Heinzel,
Max-Planck-Institut für Gravitationsphysik
(Albert-Einstein-Institut), Hannover

8 frequency decades of GW astronomy



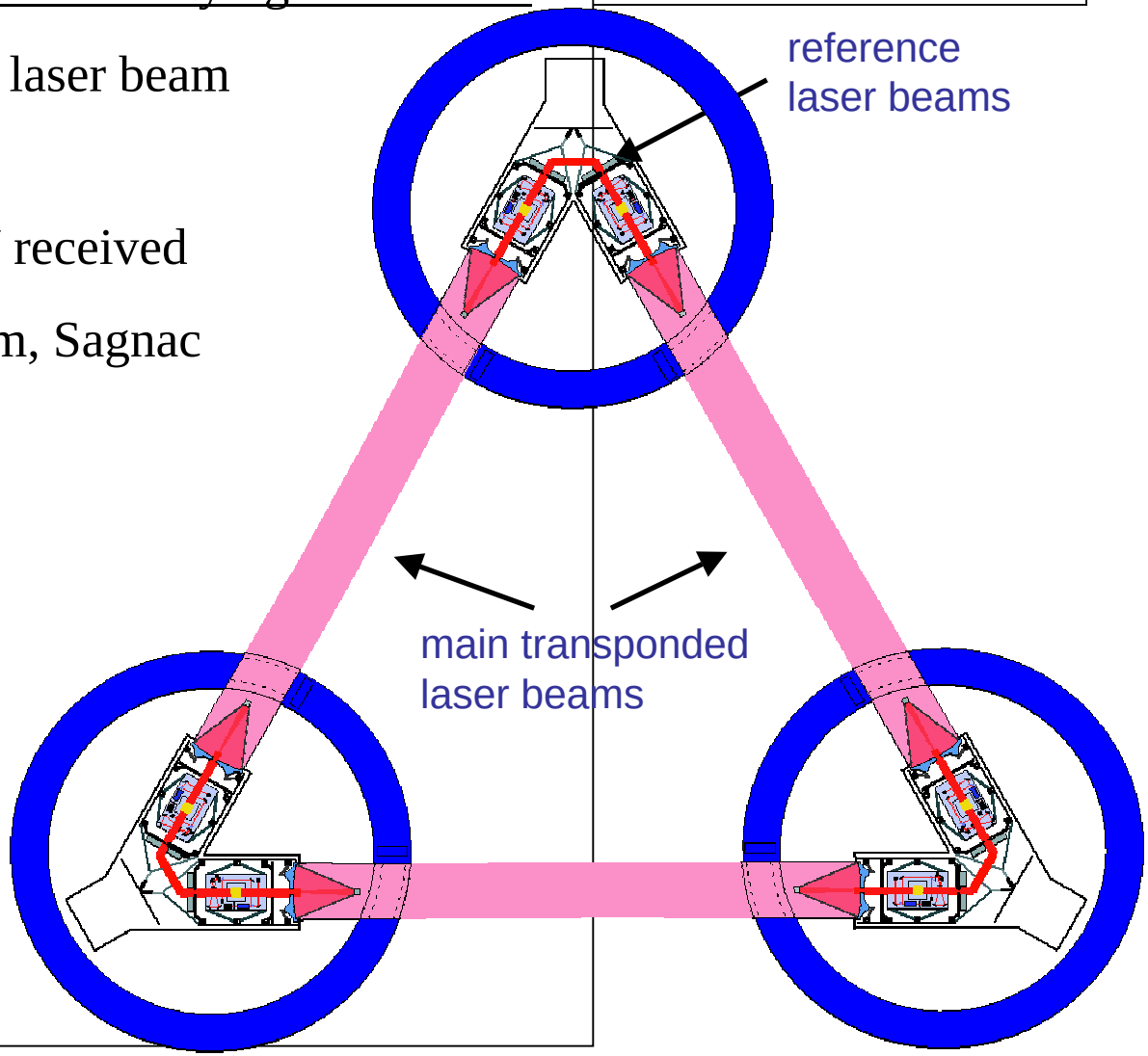
A Collaborative ESA/NASA Mission

- Cluster of 3 S/C in heliocentric orbit
- Free flying test masses shielded inside the S/C
- Trailing the earth by 20 ° (50 Mio km)
- Equilateral triangle with 5 Mio km arms
- Inclined against ecliptic by 60 °

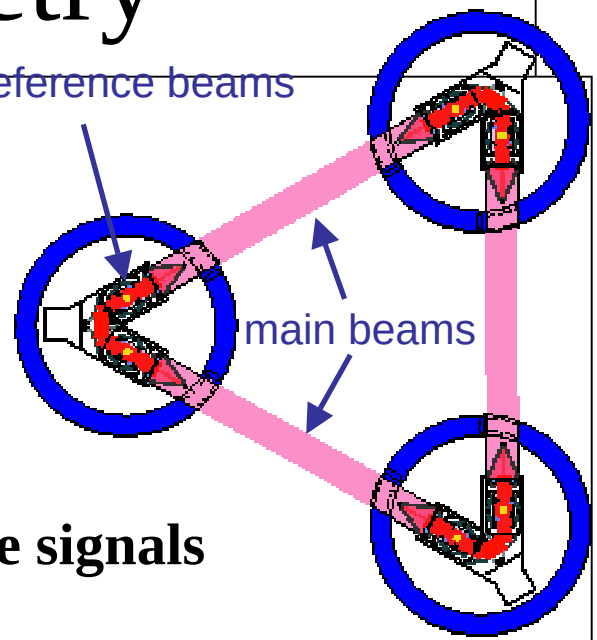


LISA layout

- Laser beams reflected off free-flying test masses
- Diffraction widens the laser beam to many kilometers
  - 0.7 W sent, 70 pW received
- Michelson with 3rd arm, Sagnac
- Can distinguish both polarizations of a GW
- Orbital motion provides direction information



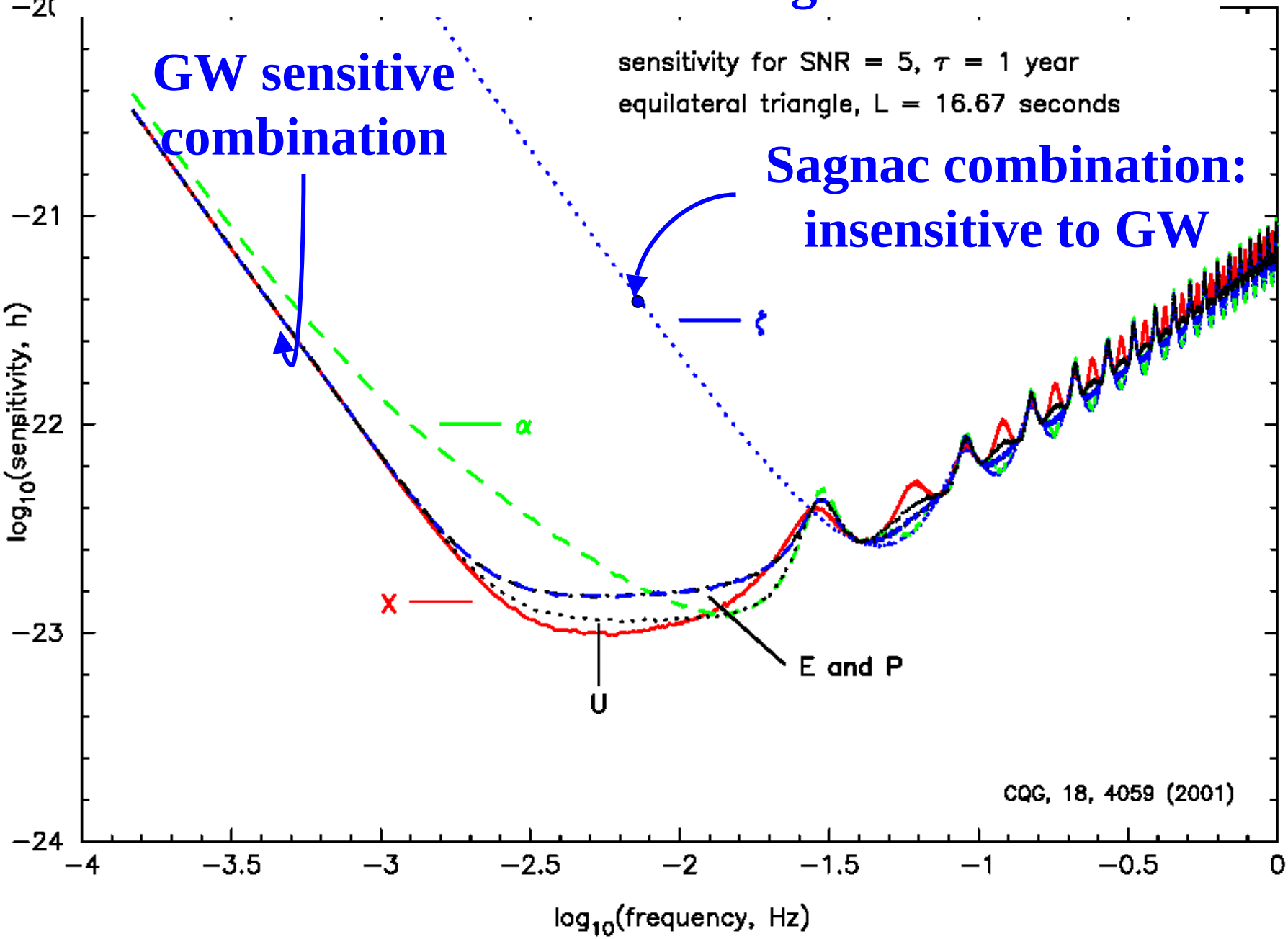
LISA Interferometry

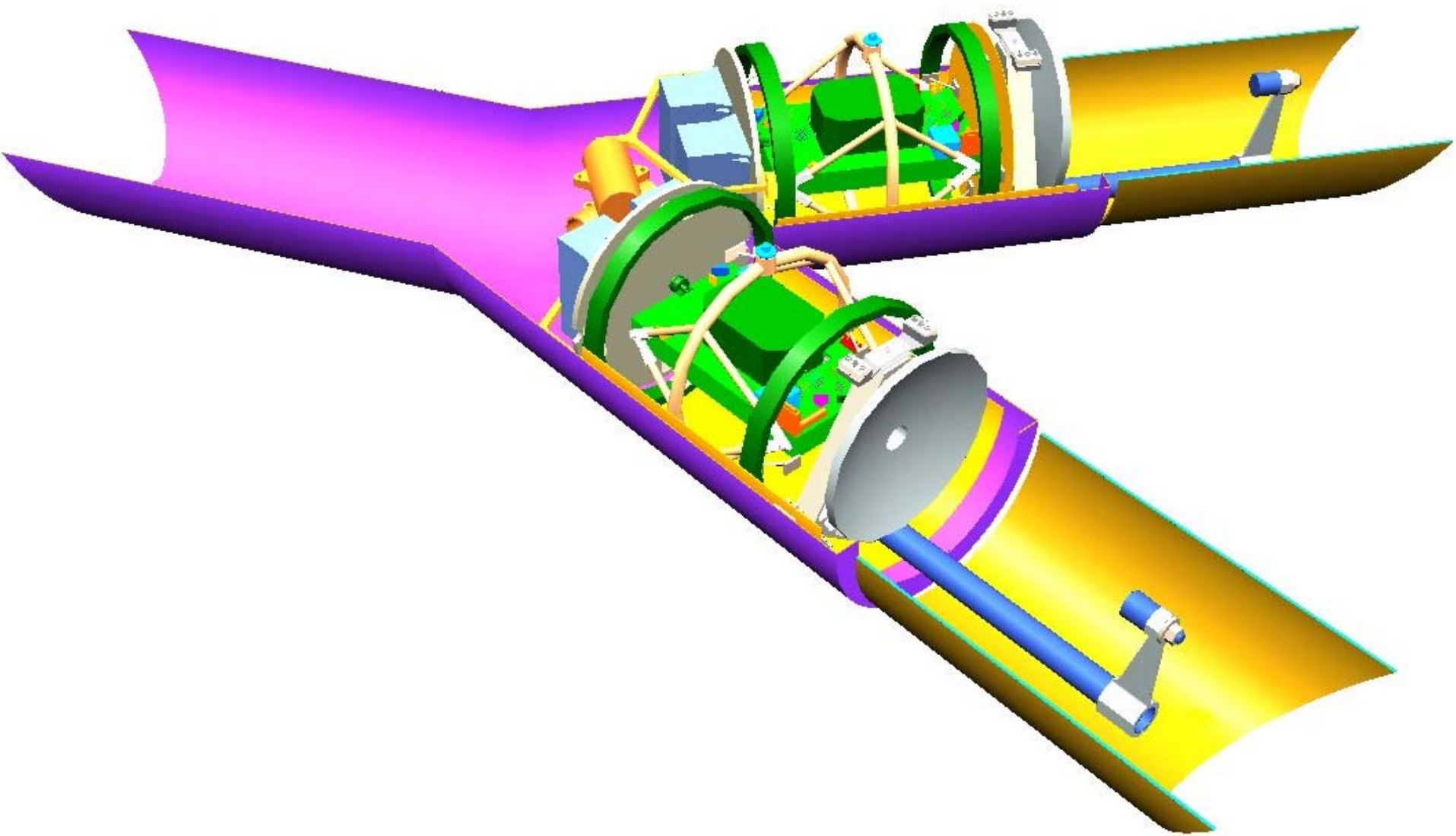


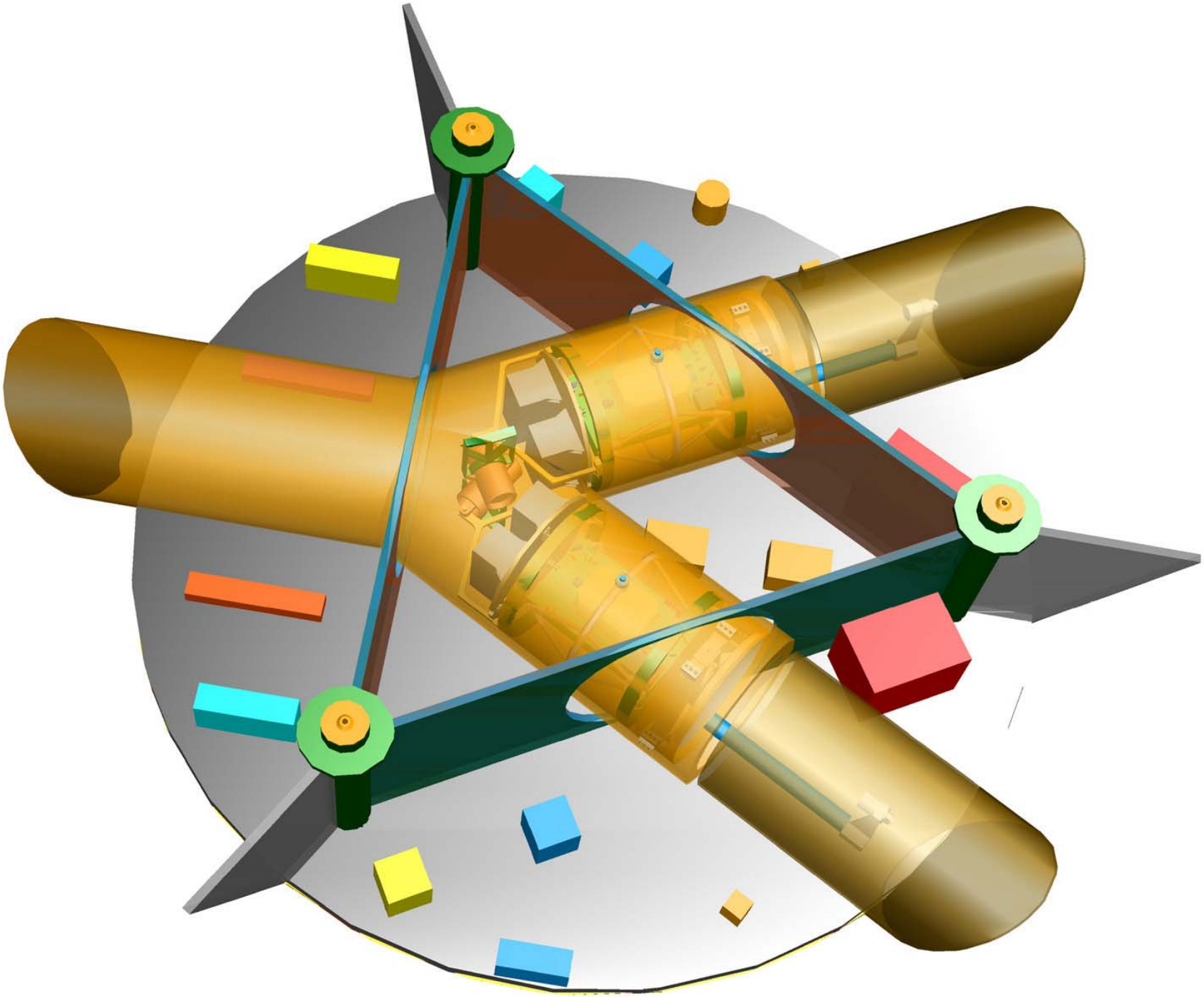
- **Each beam (reference and main) is separately heterodyned with the local laser on a photodiode**
- ***Time-delay Interferometry (Tinto, Vinet, Shaddock et al):***
- **Specific linear combinations of heterodyne signals in time domain cancel laser/USO noise and keep GW signal**
- **One linear combination cancels the GW signal and laser/USO noise**

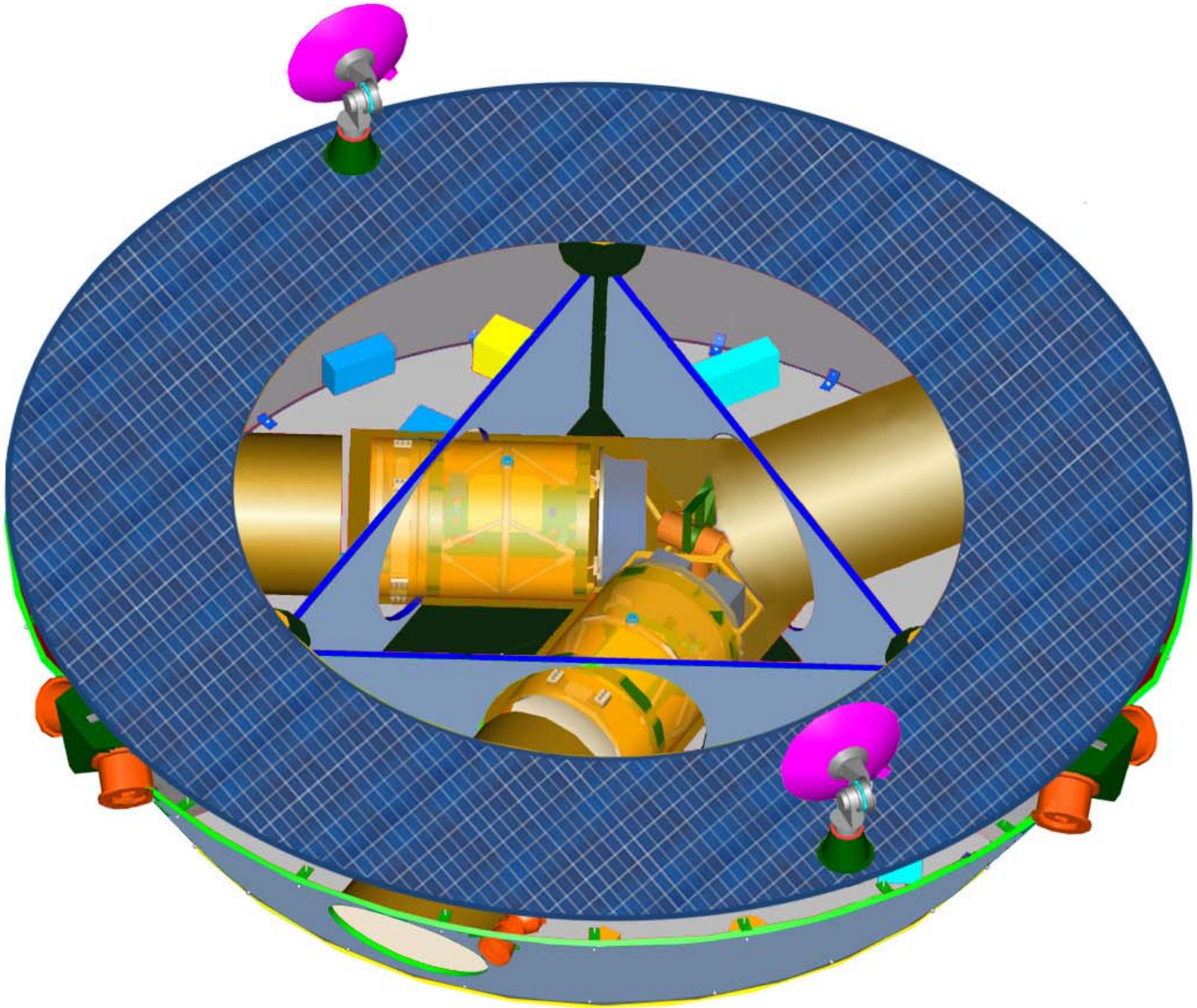
$\Rightarrow$ LISA can distinguish a stochastic gravitational wave background from instrumental noise background!

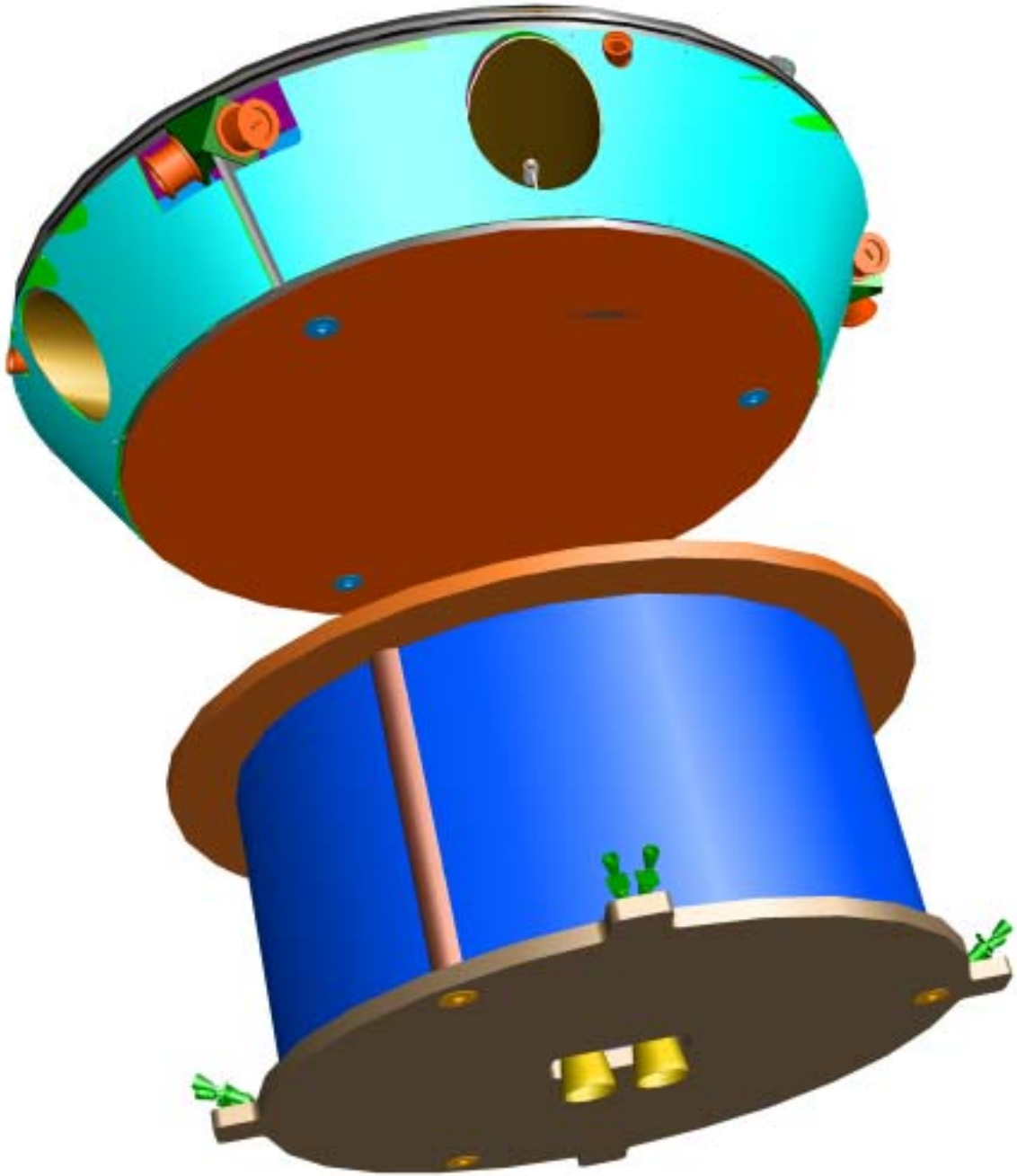
Allows calibration of background noise

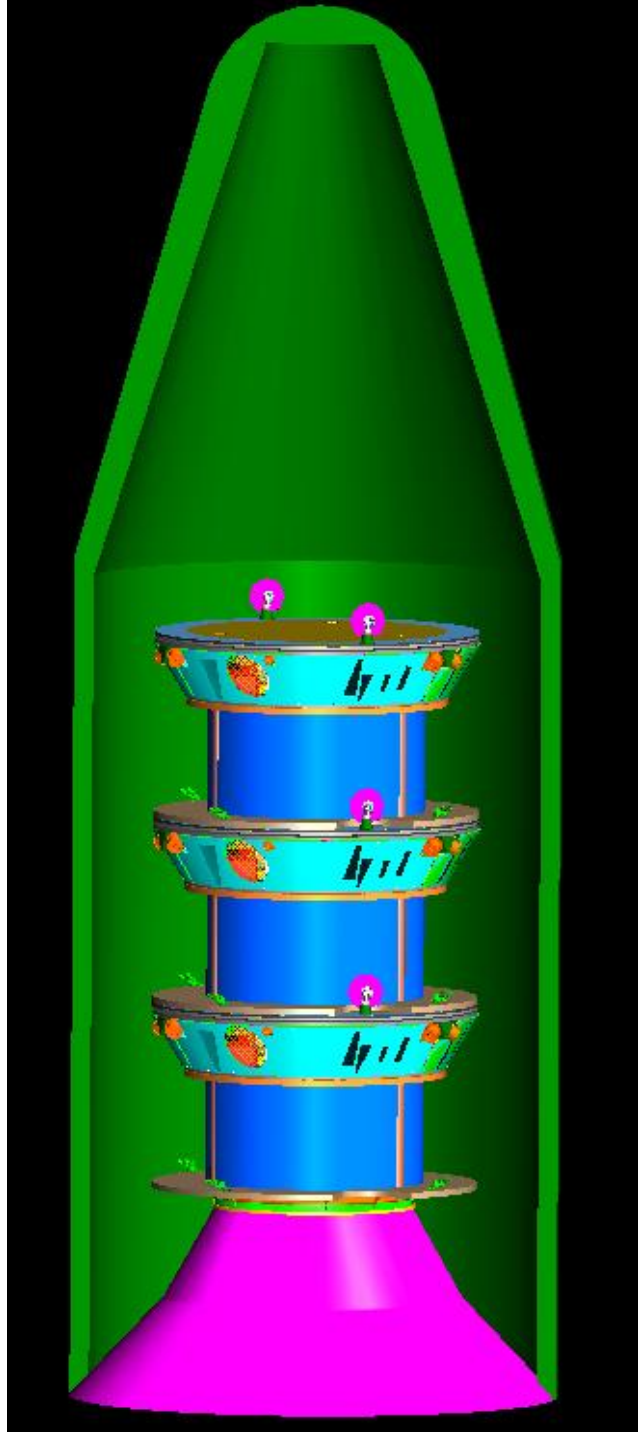






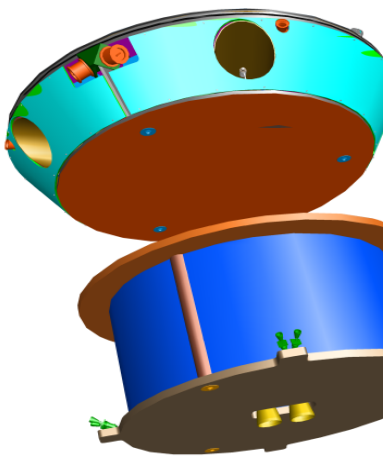


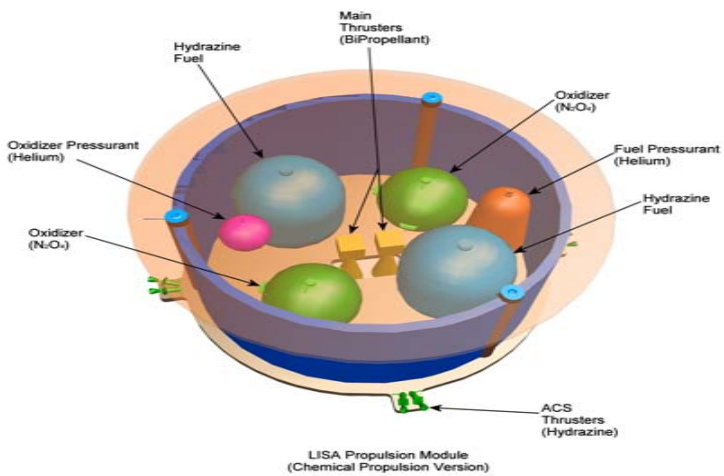




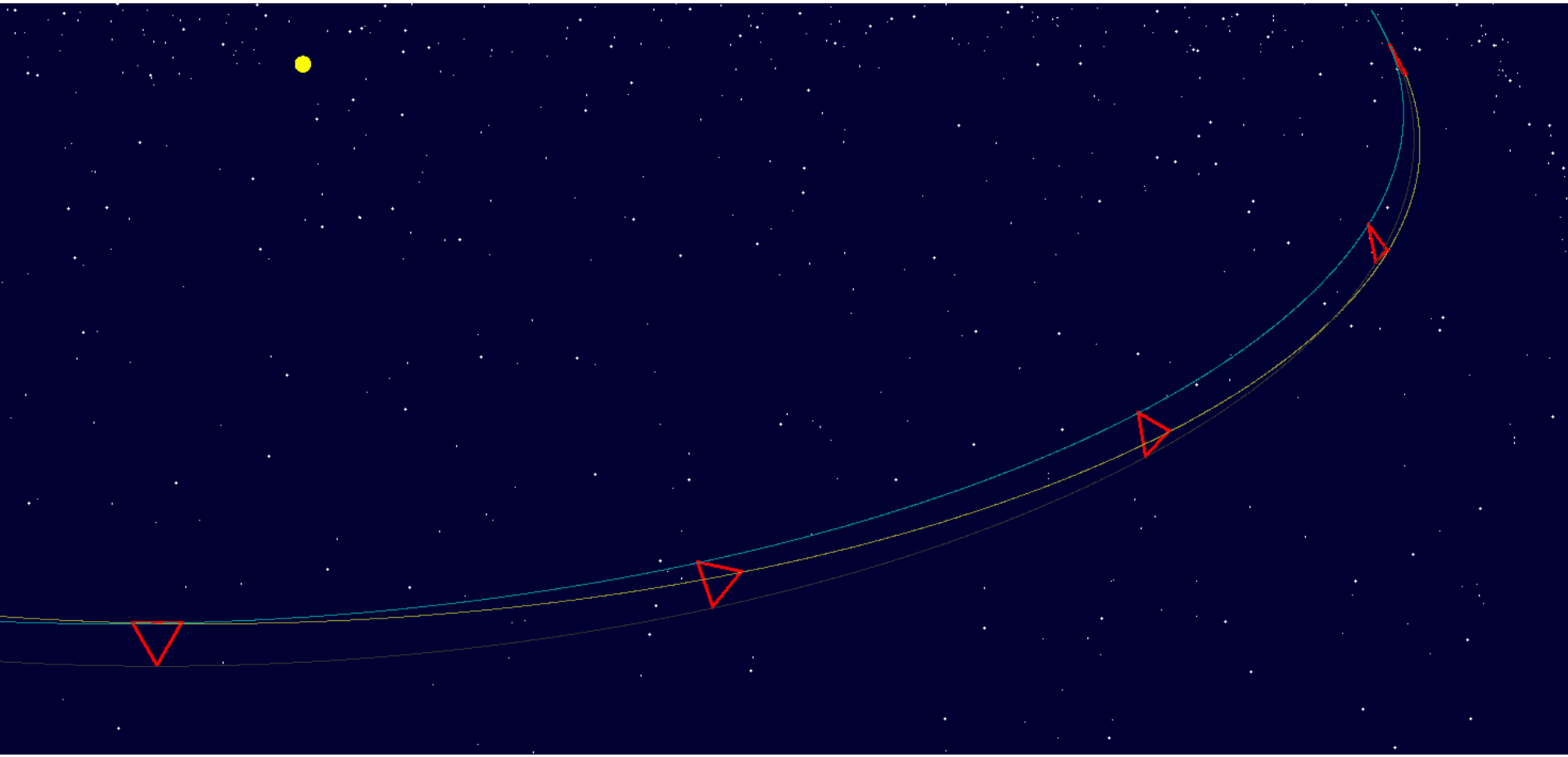
LISA Launch and Cruise

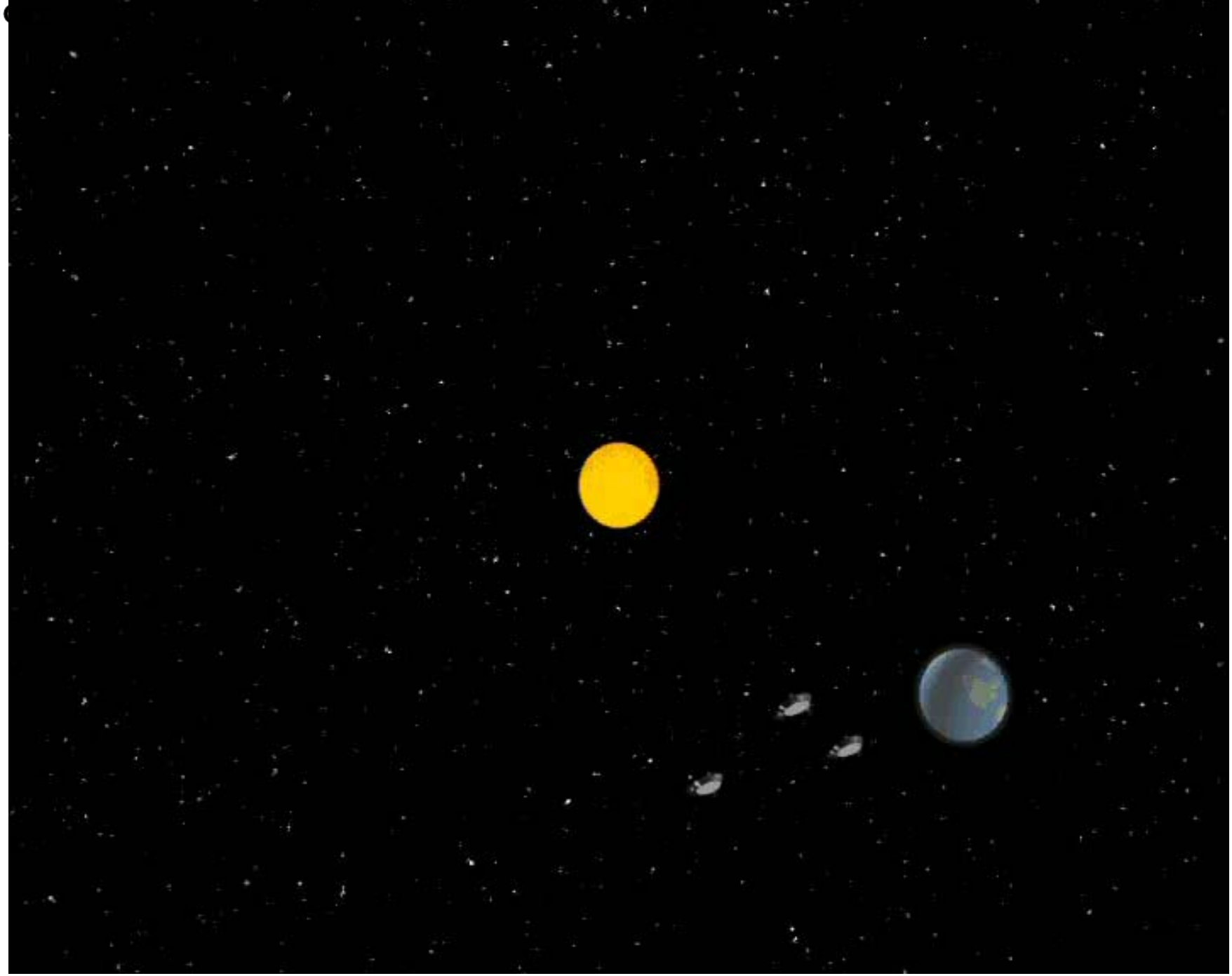
- Delta IV medium launches all three spacecraft
- Each spacecraft is attached to its own propulsion module
  - Propulsion Module ΔV = 1.22 km/sec
  - Propulsion module incorporates a bipropellent (N_2O_4 / hydrazine) system and a Reaction Control System for attitude control
- 13 month cruise phase





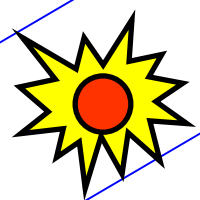
LISA essentials 1: the smart orbits

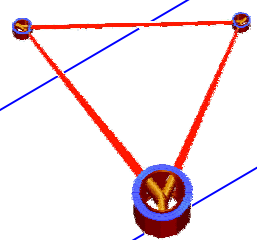




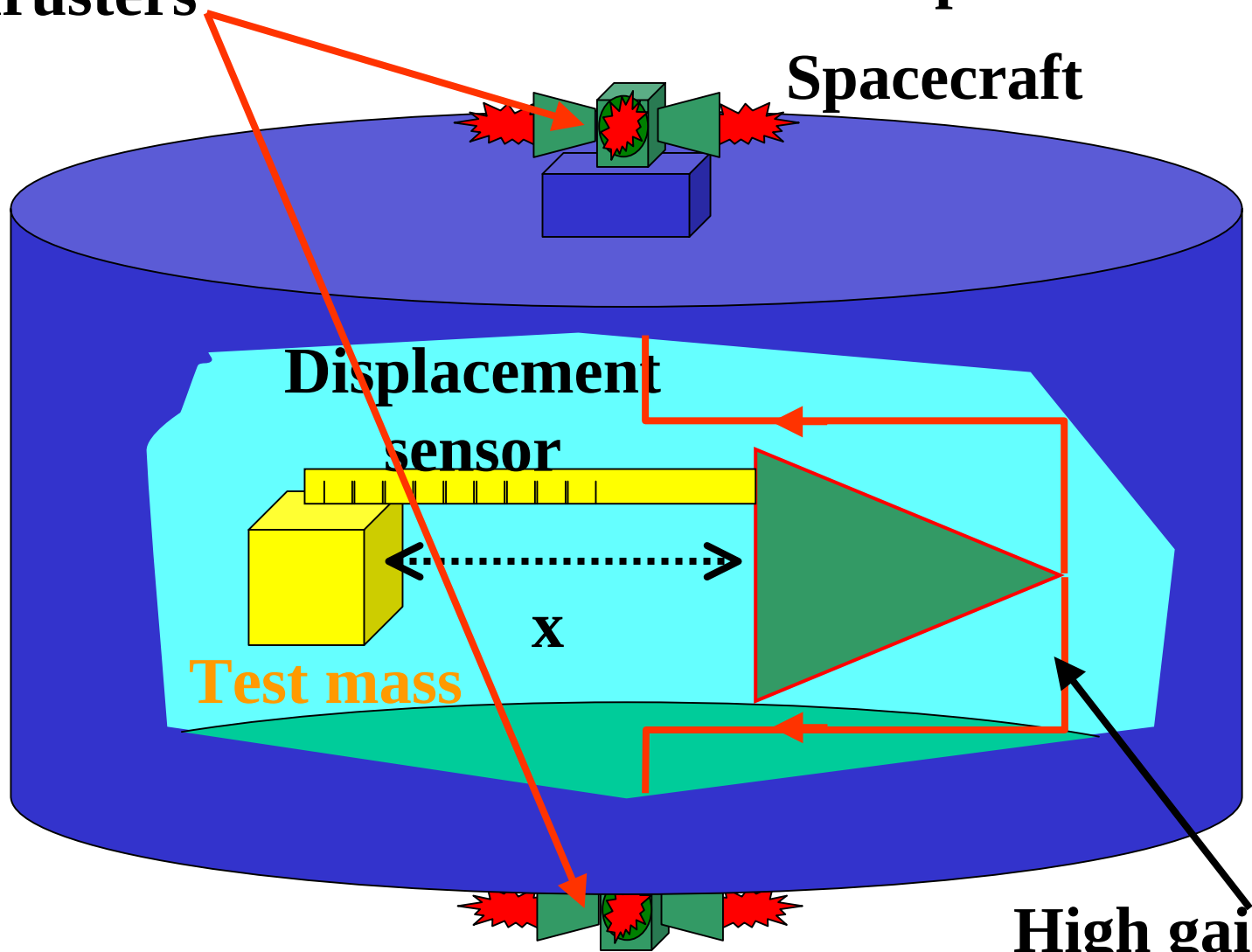
Angular Resolution with LISA

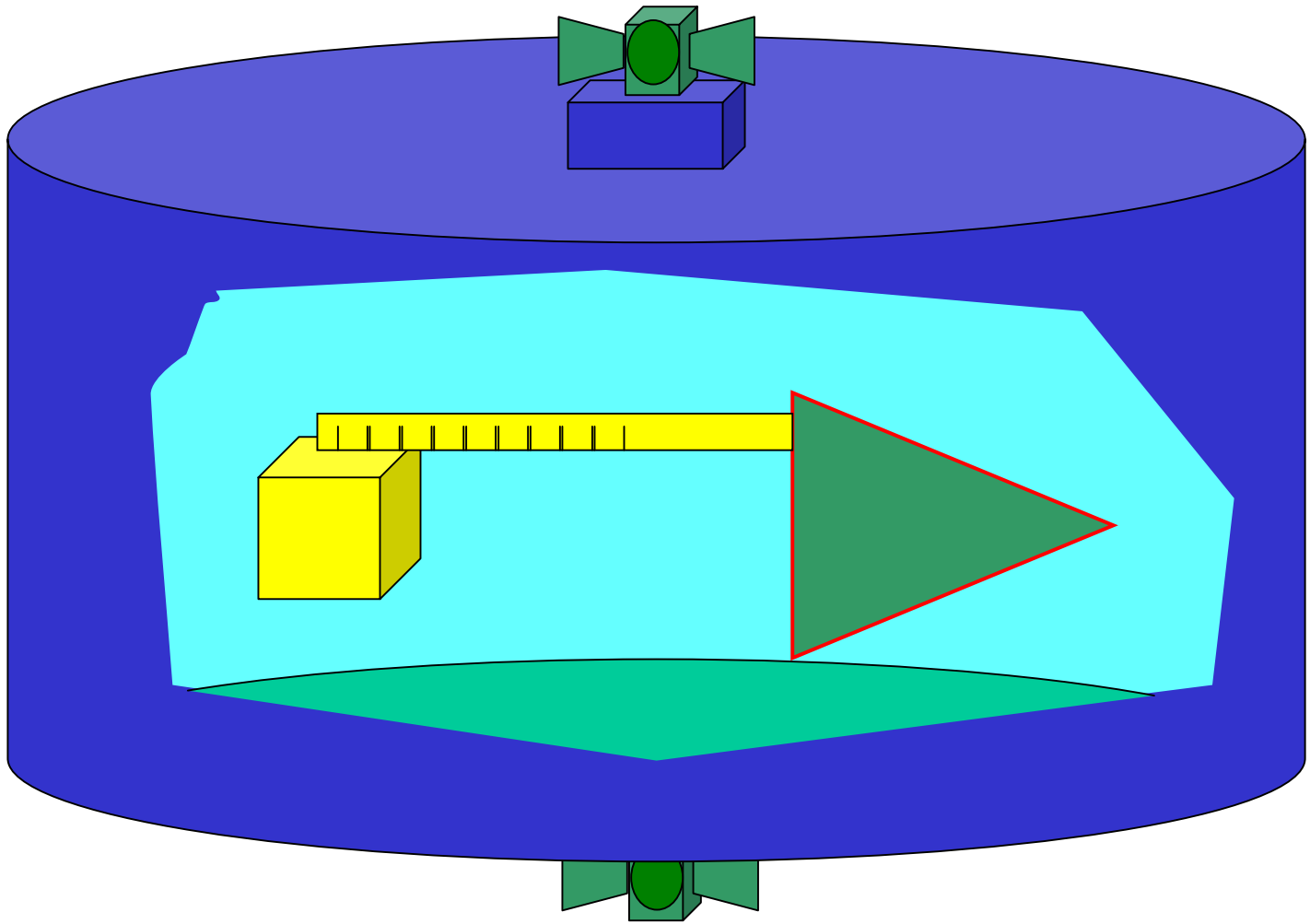
- Measurements on detected sources:
  - $\Delta\theta \sim 1' - 1^{o}$
  - $\Delta(\text{mass,distance}) \leq 1\%$

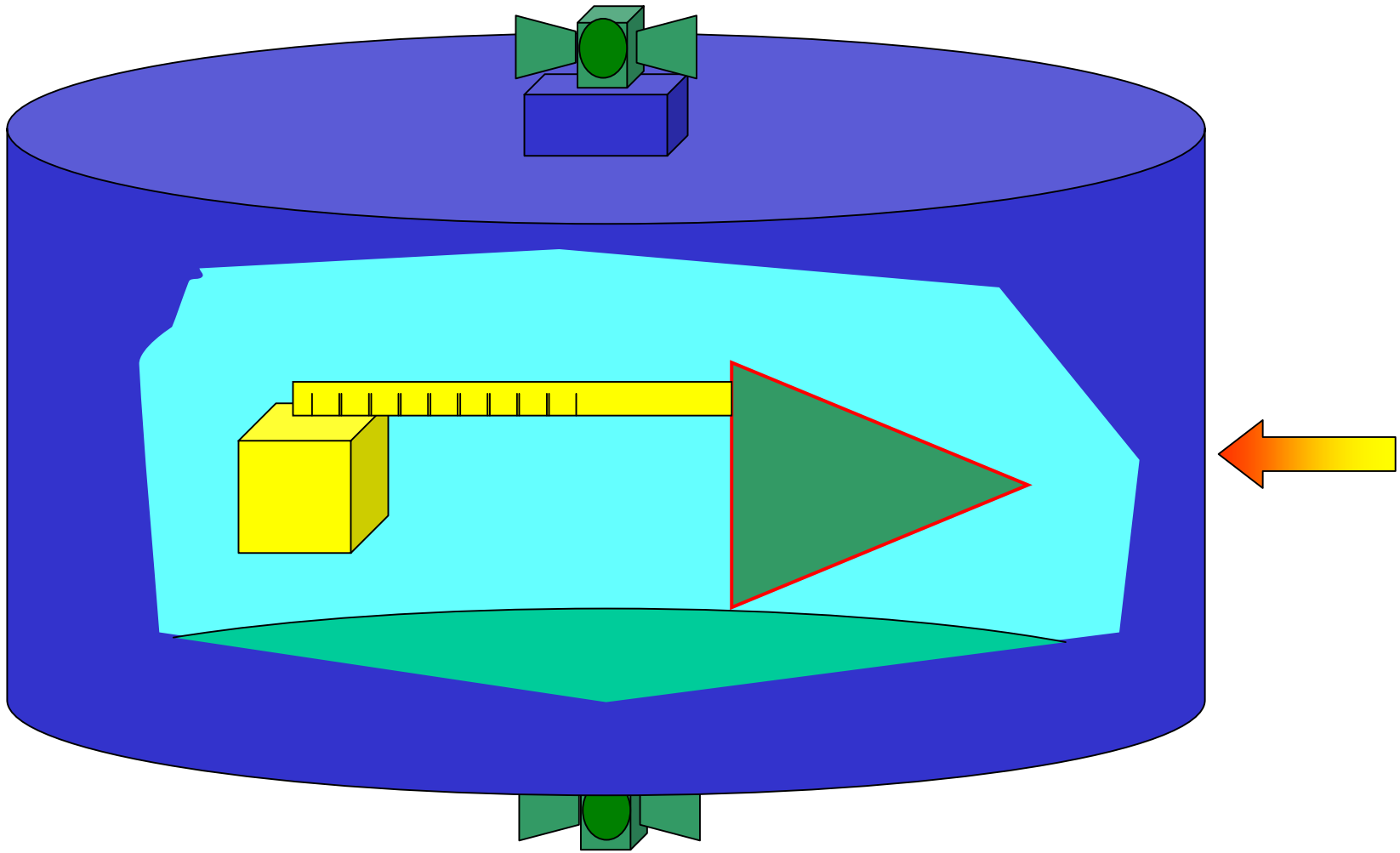


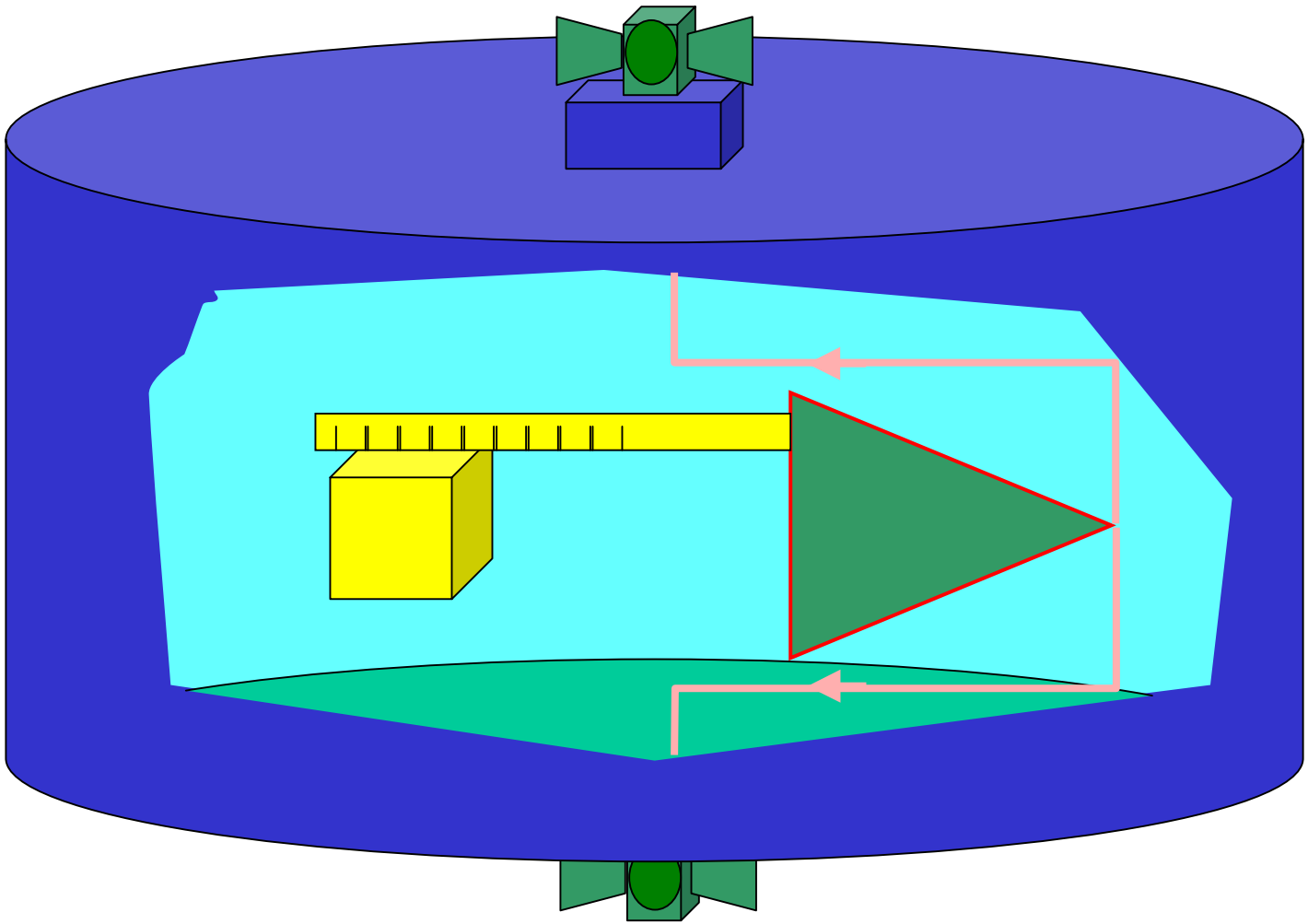


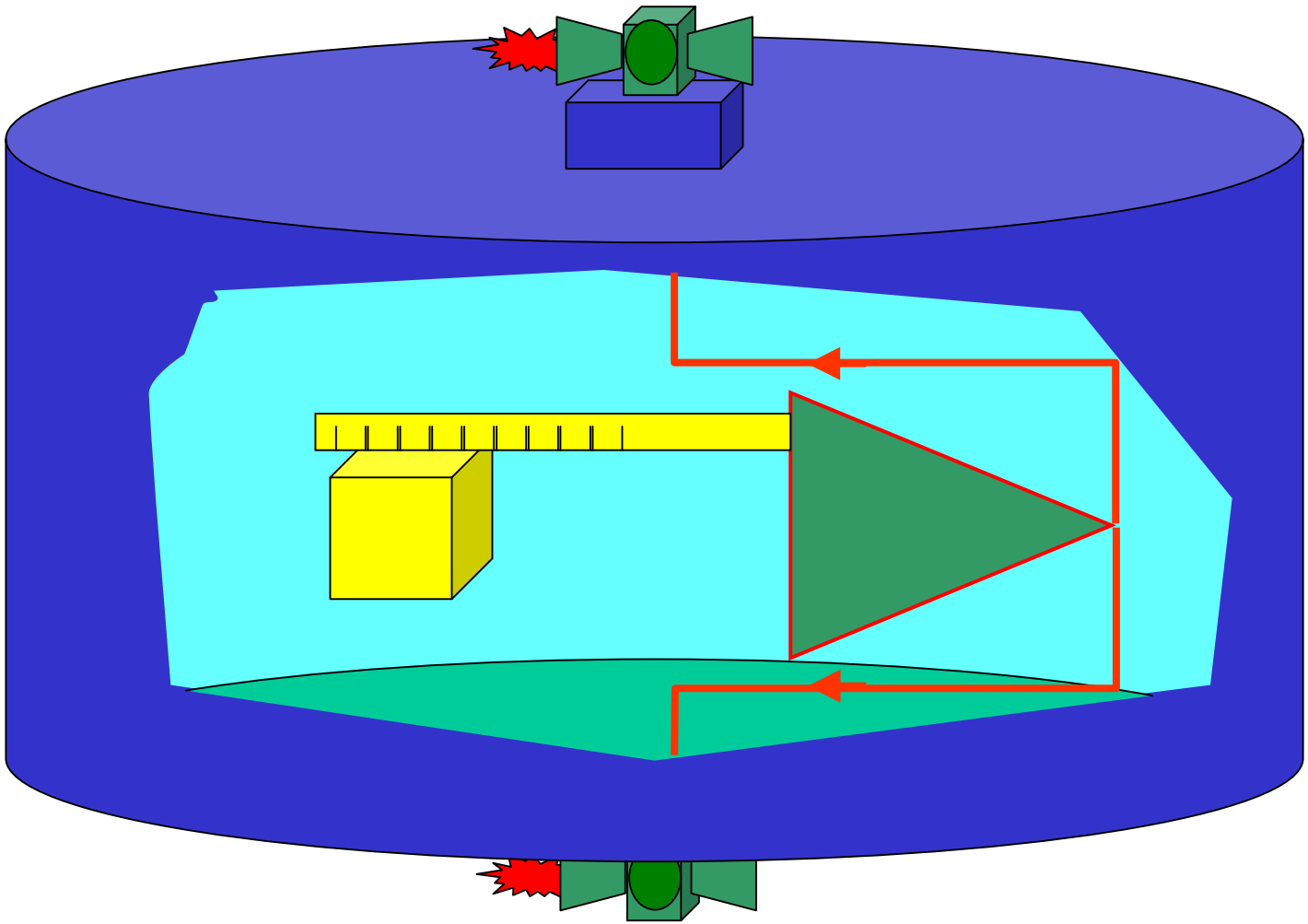
Drag-free: keeping the spacecraft with the proof-mass

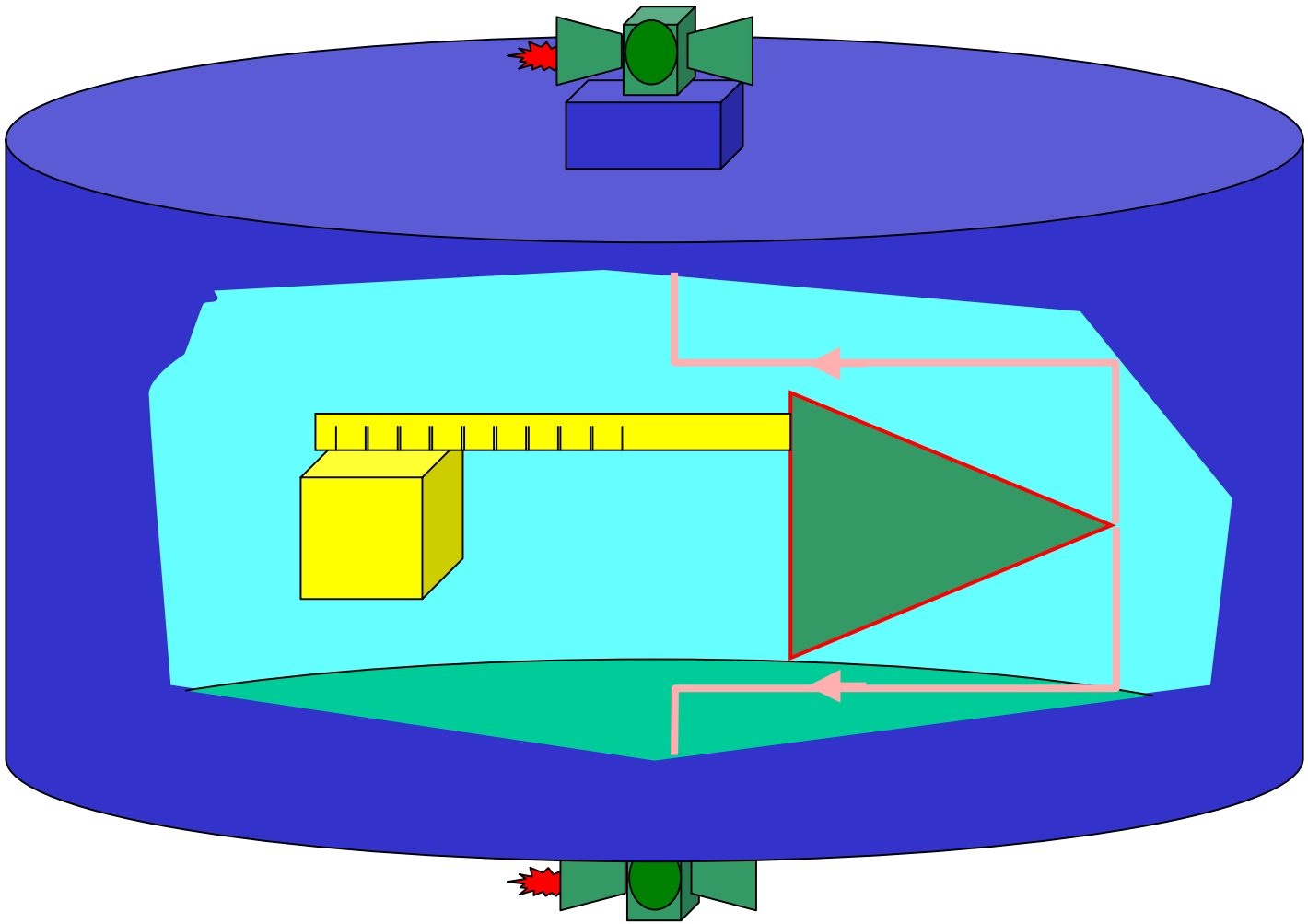


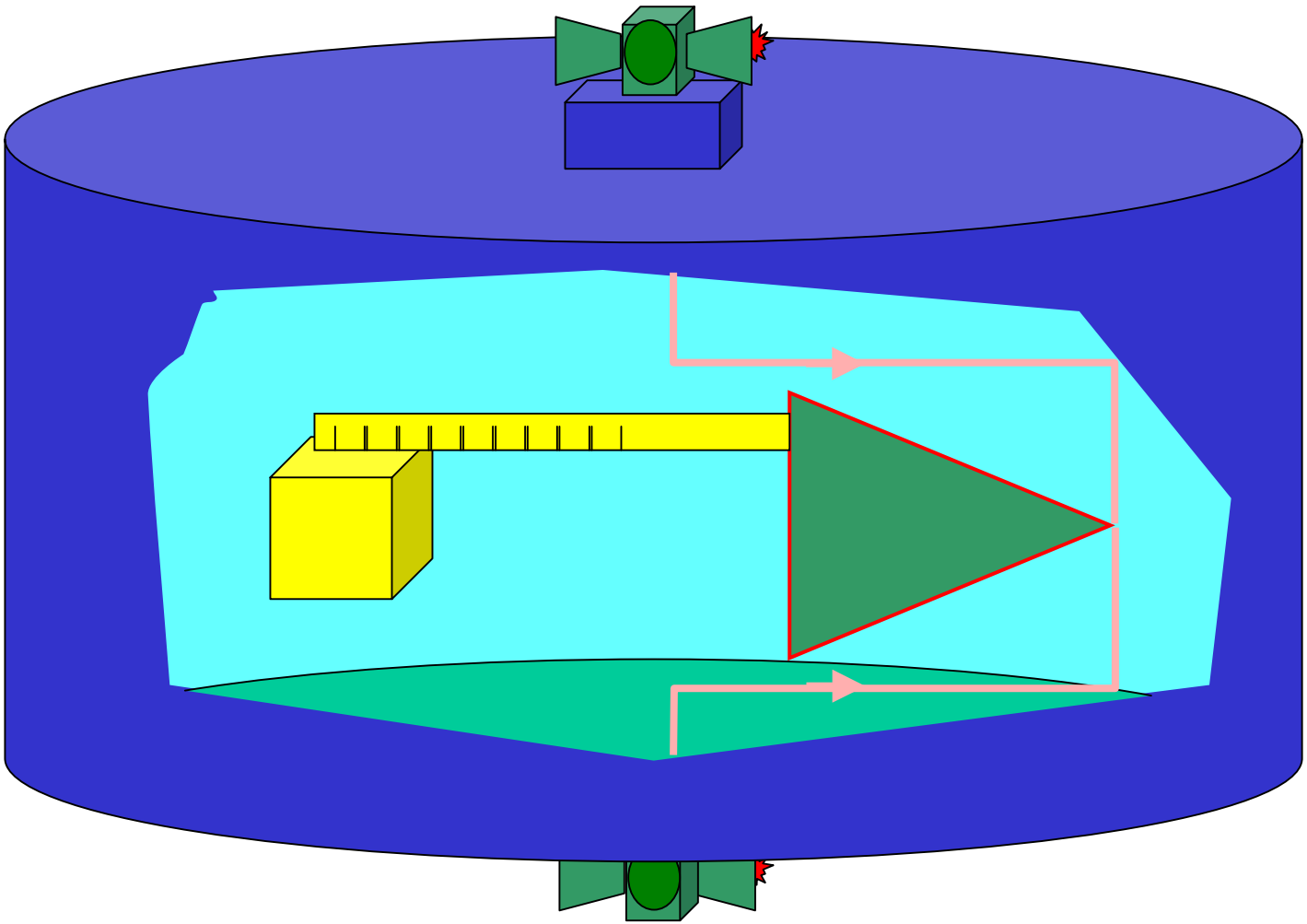


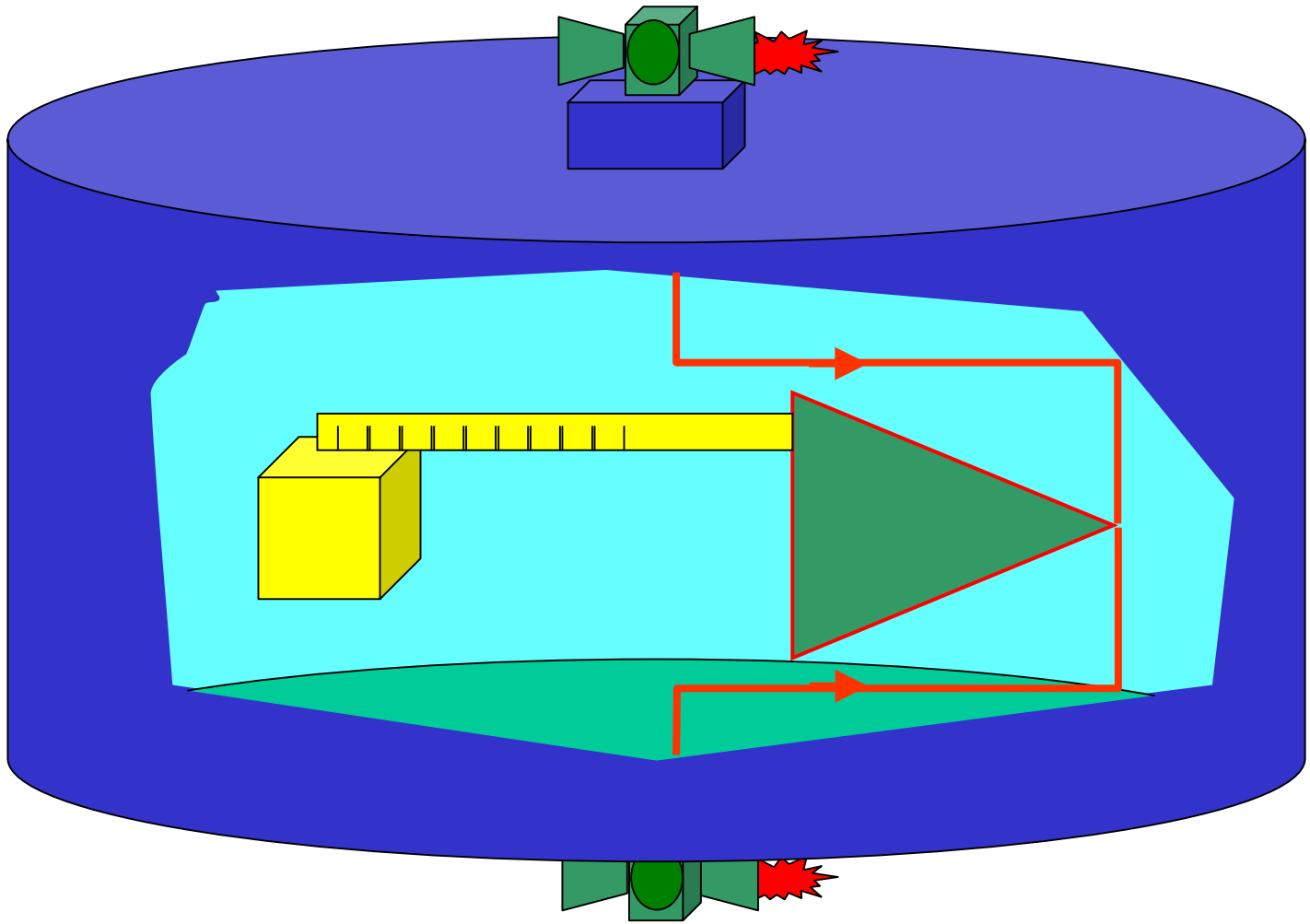


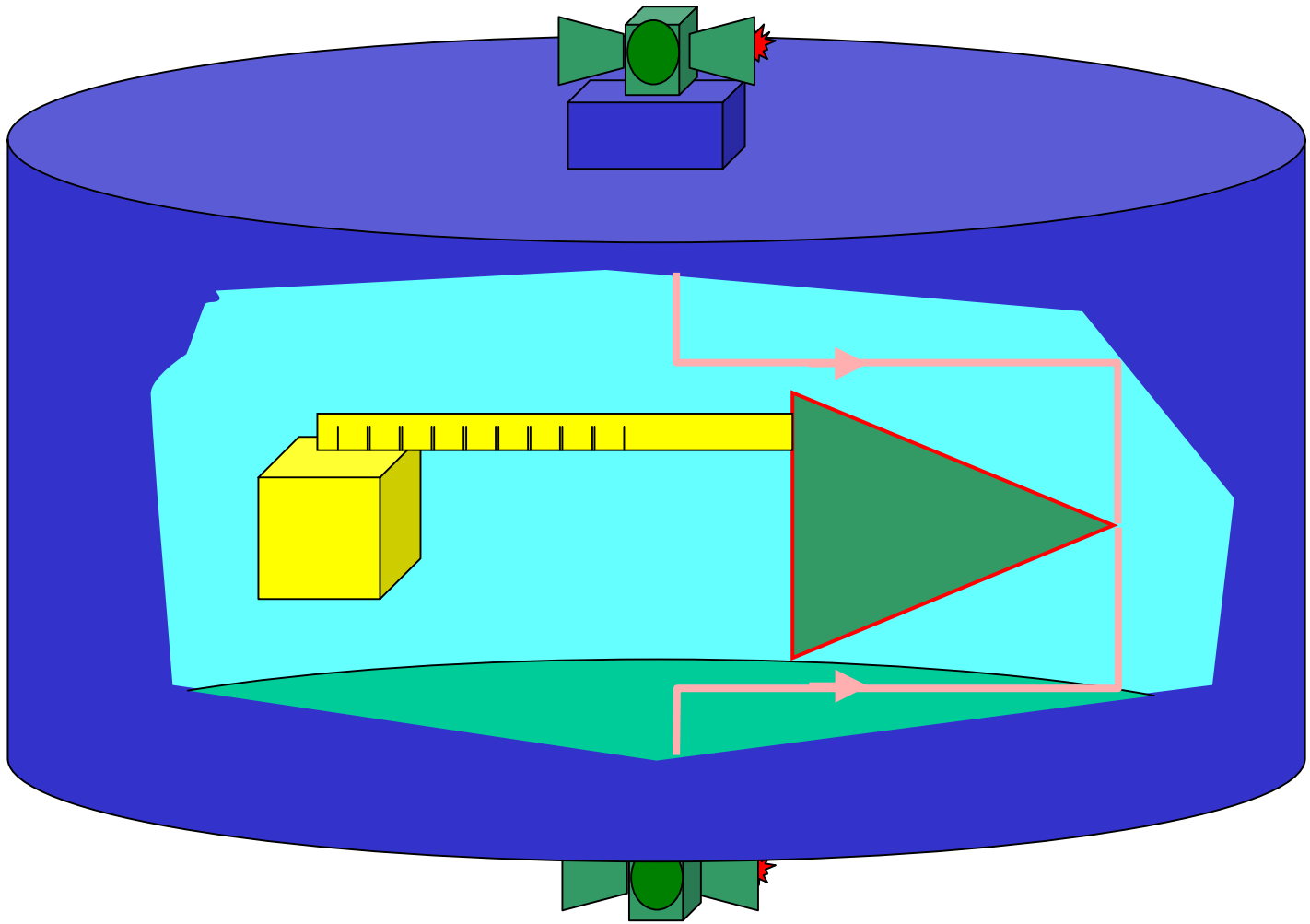


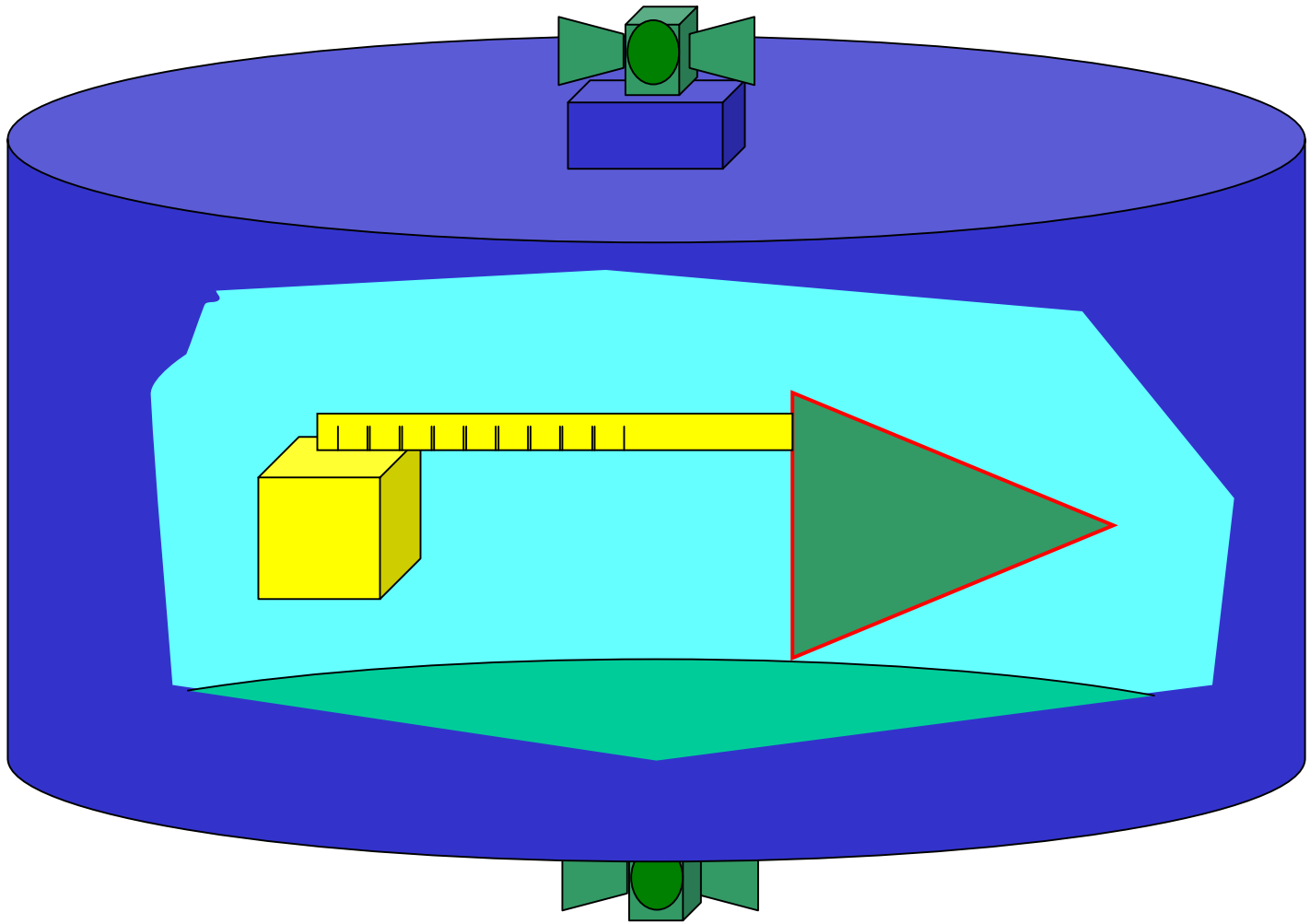


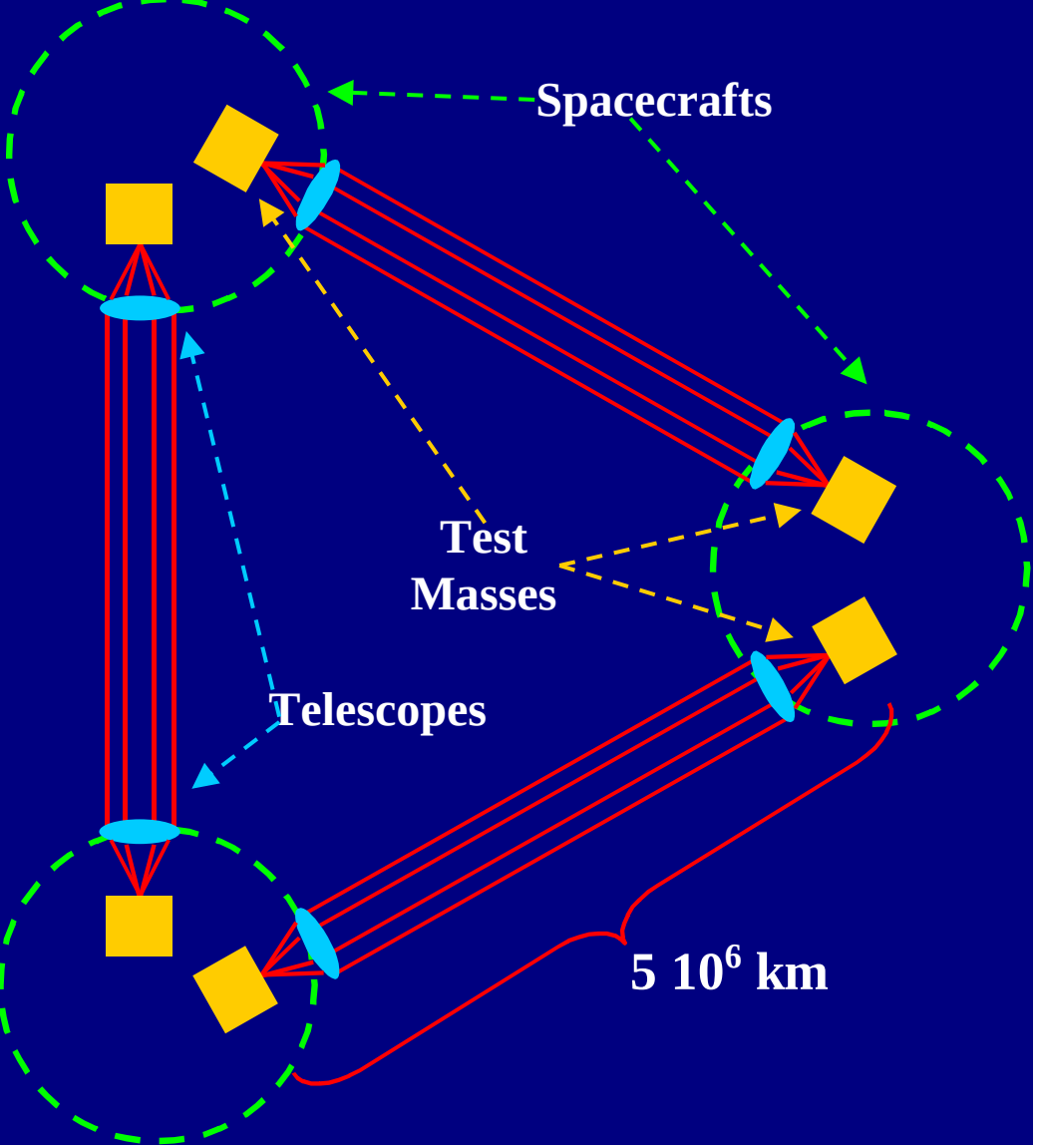










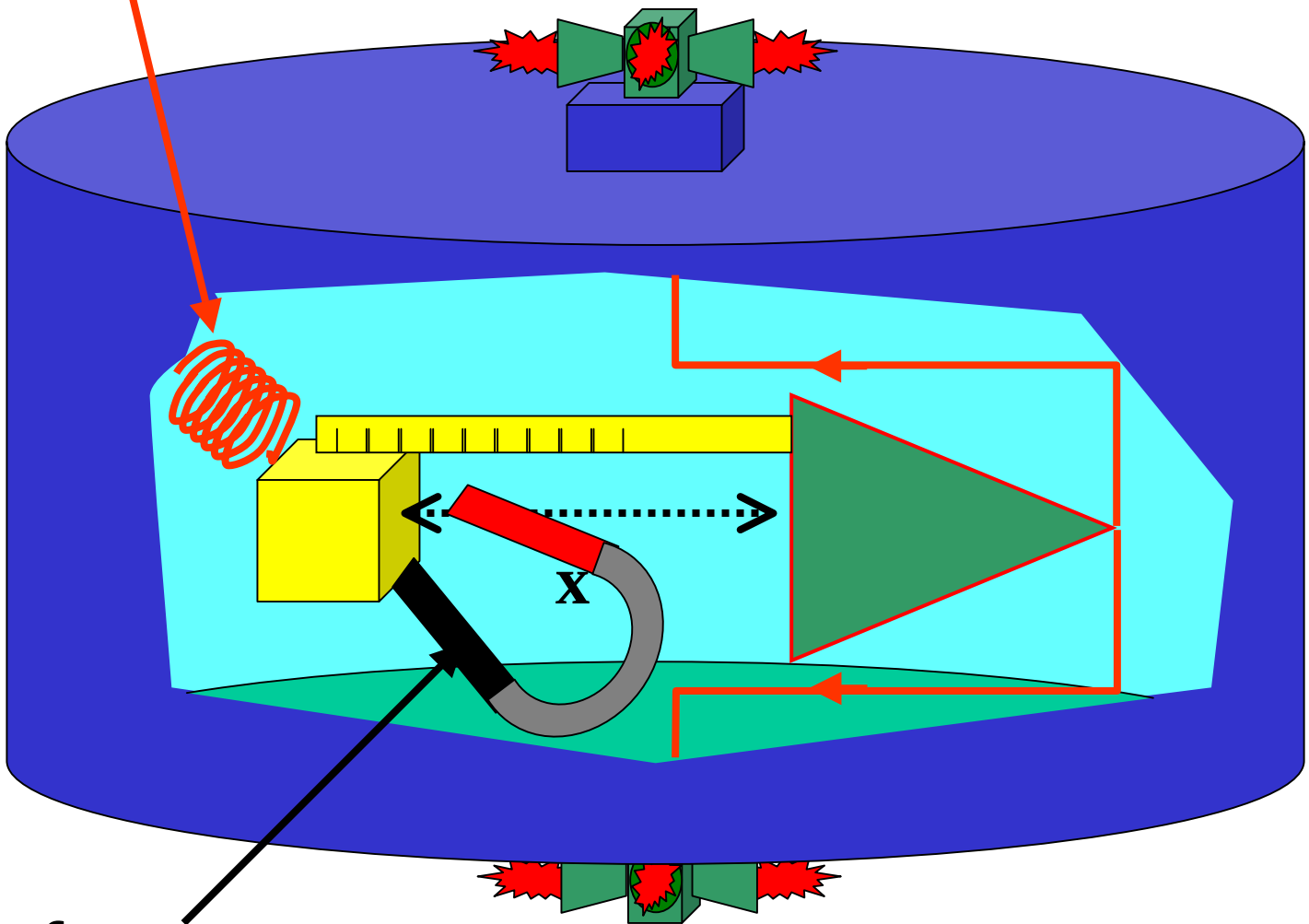


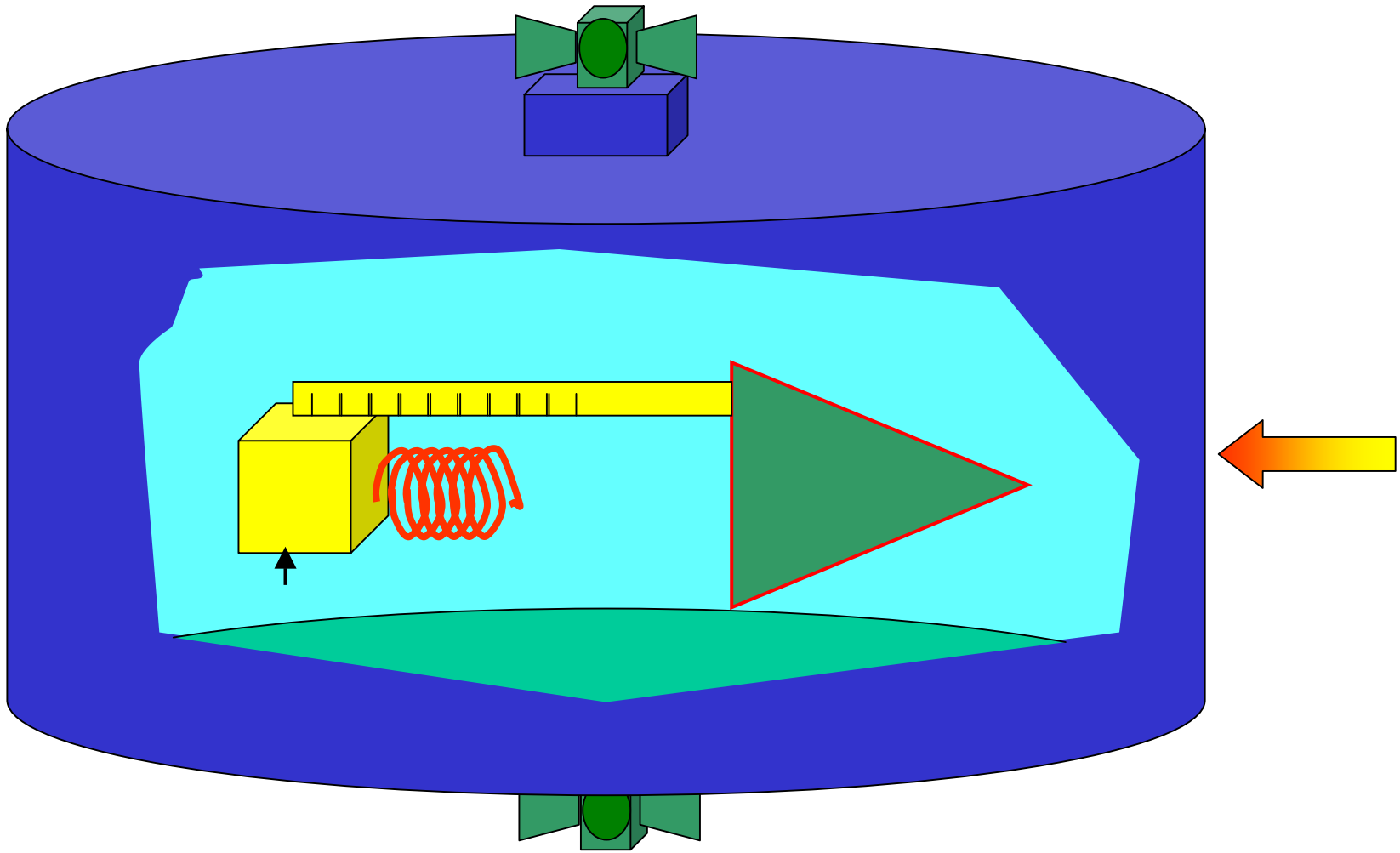
3 pairs of "free falling" test masses
(3 10^{-15} ms^{-2} $Hz^{-1/2}$ @ 0.1 mHz)

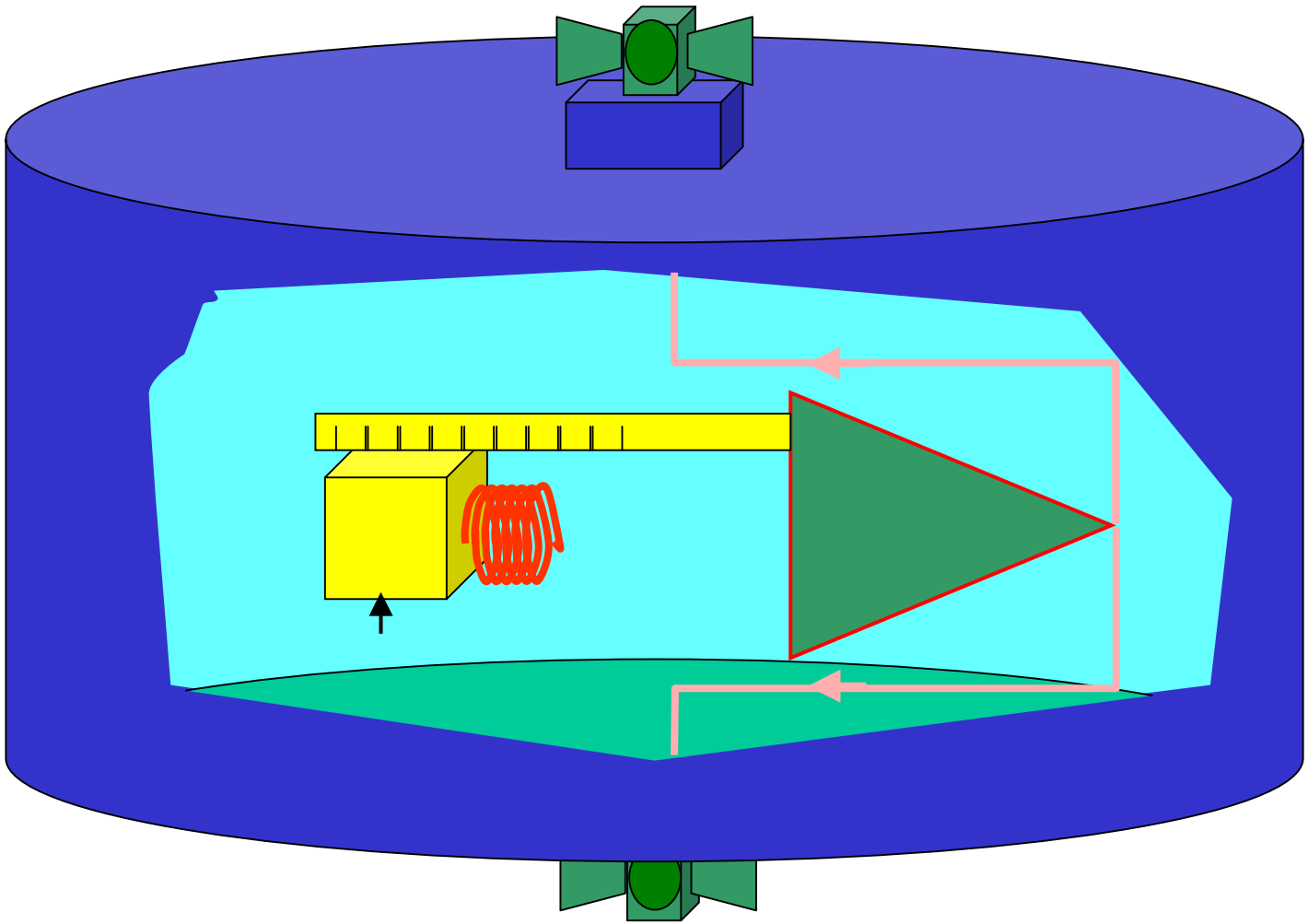
Can it be achieved?

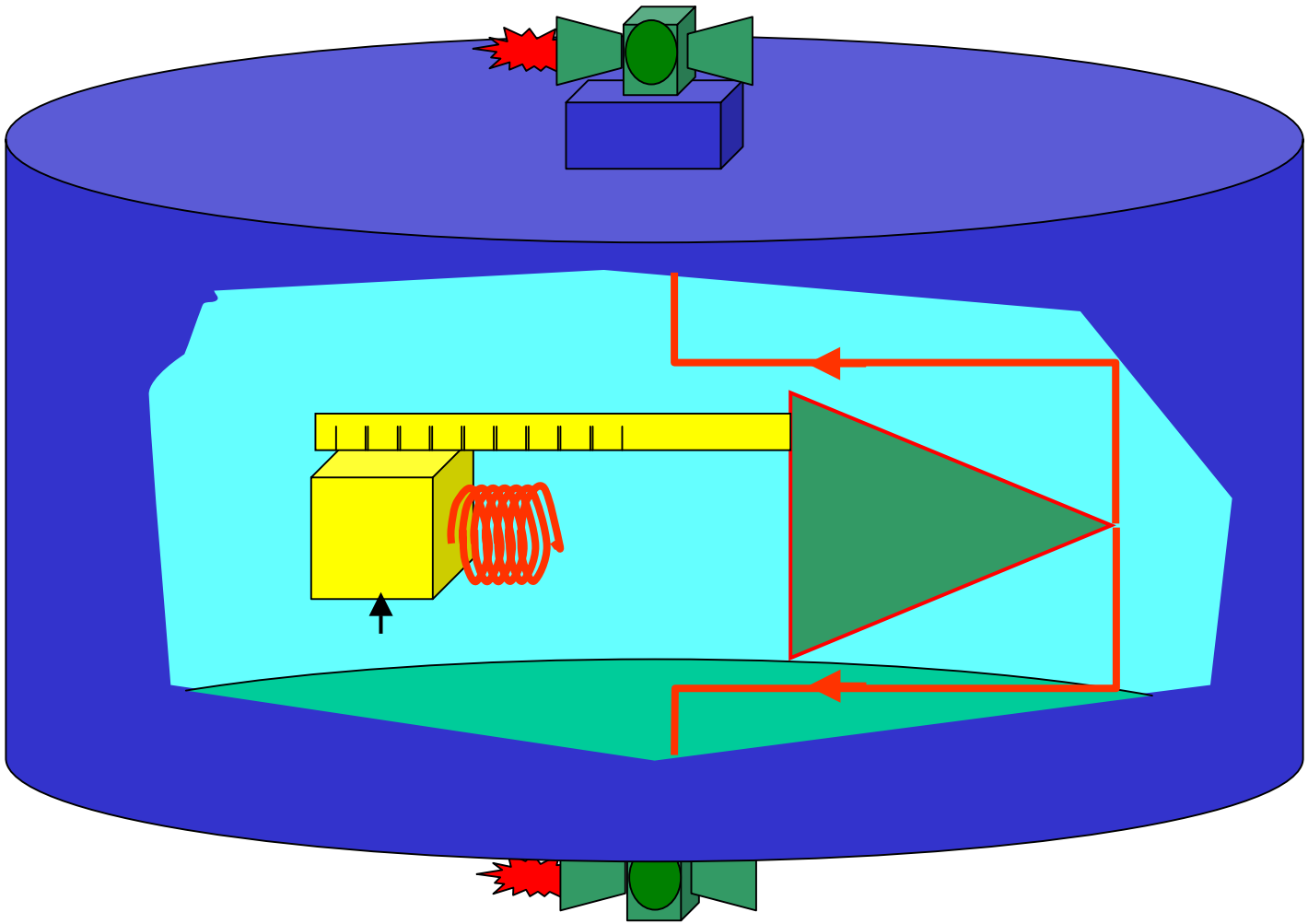
Can it be tested?

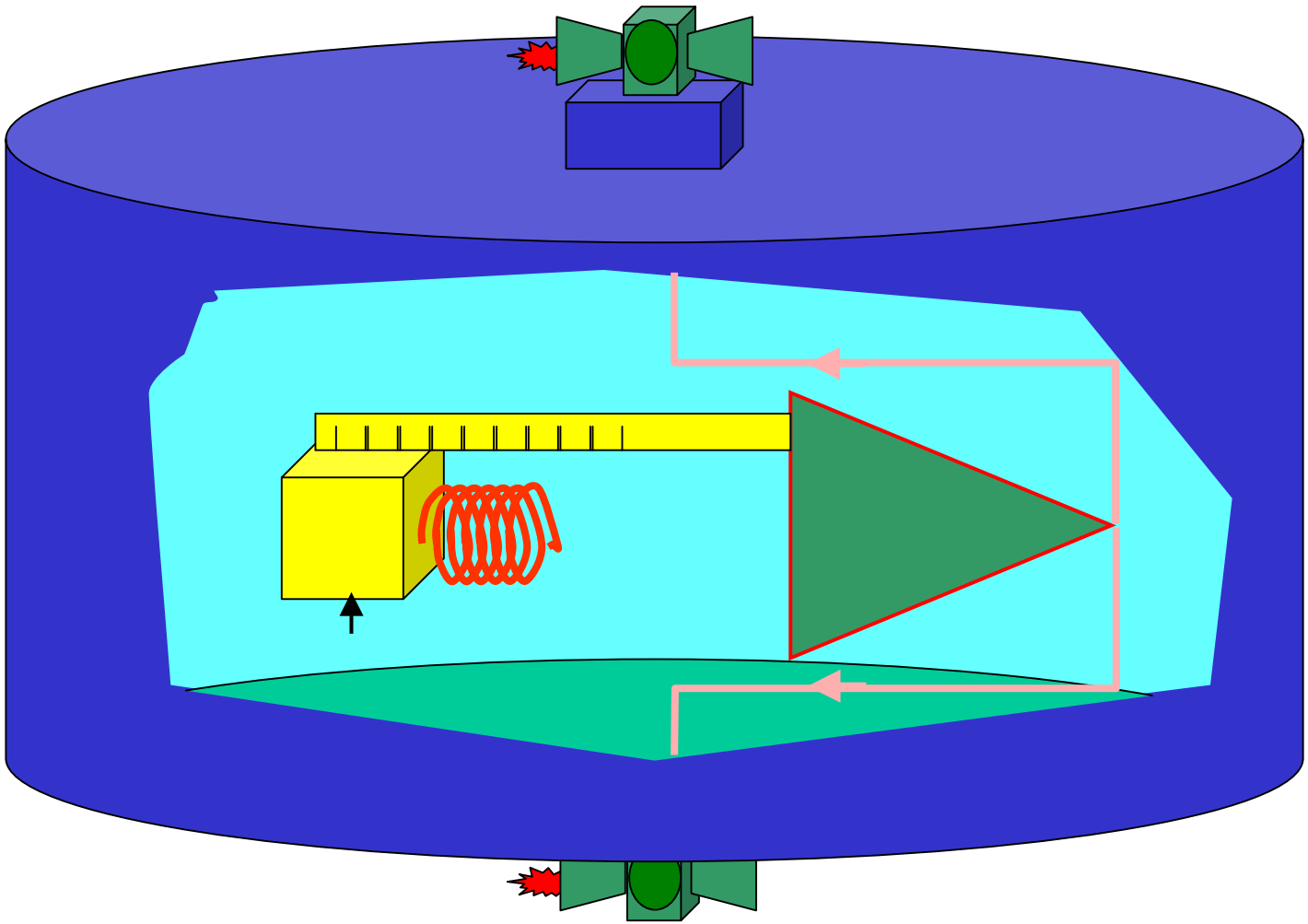
The reality

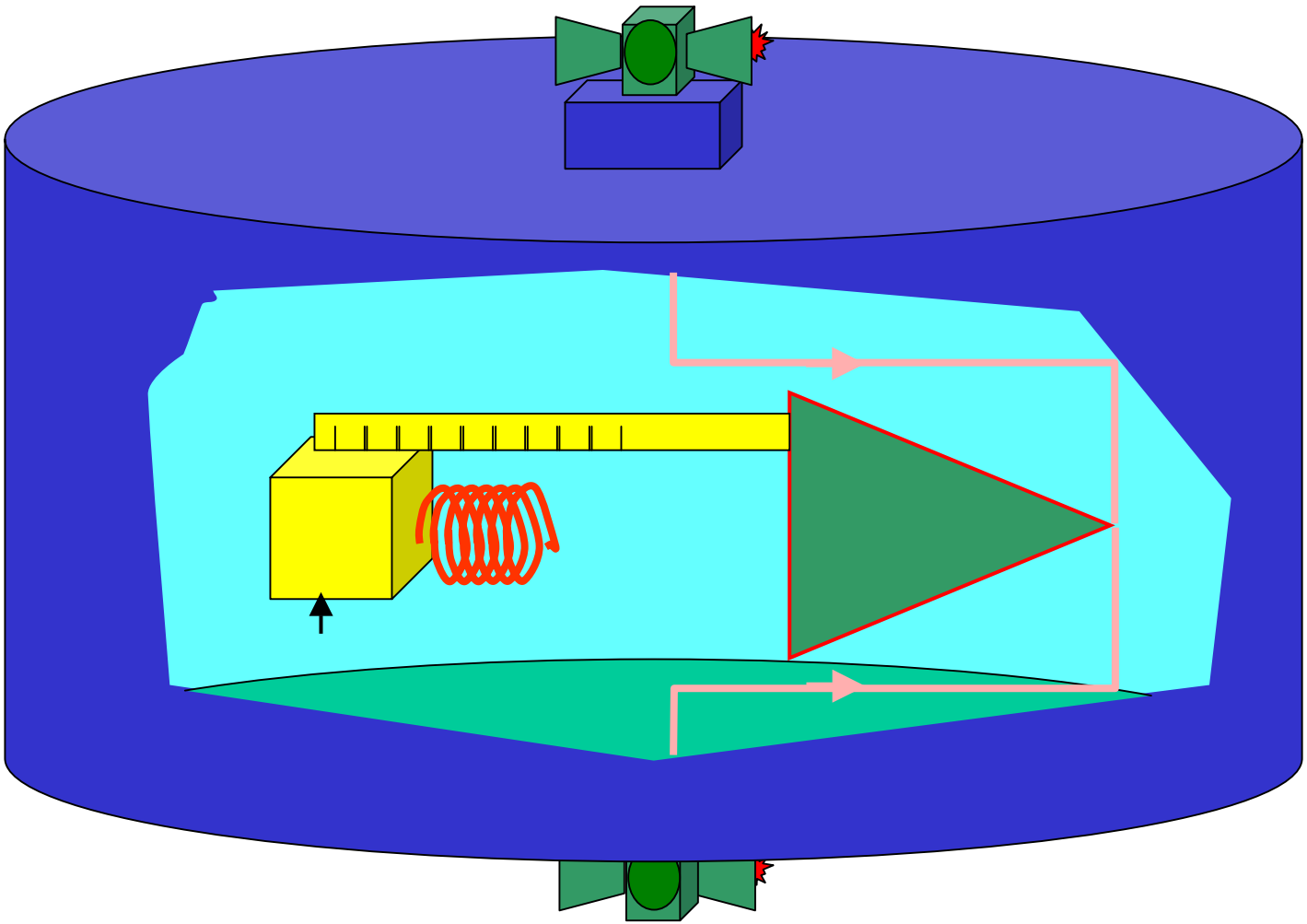


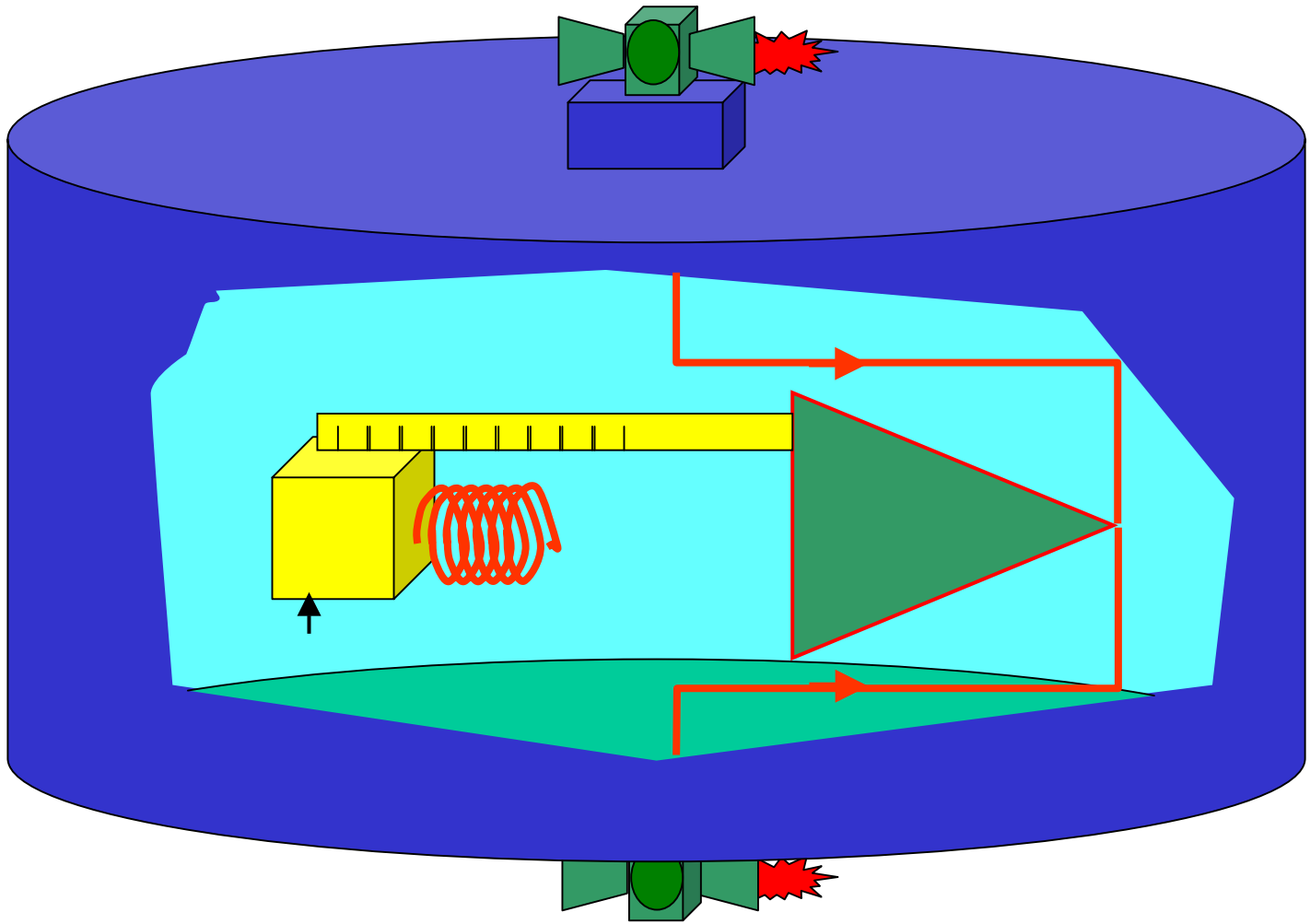


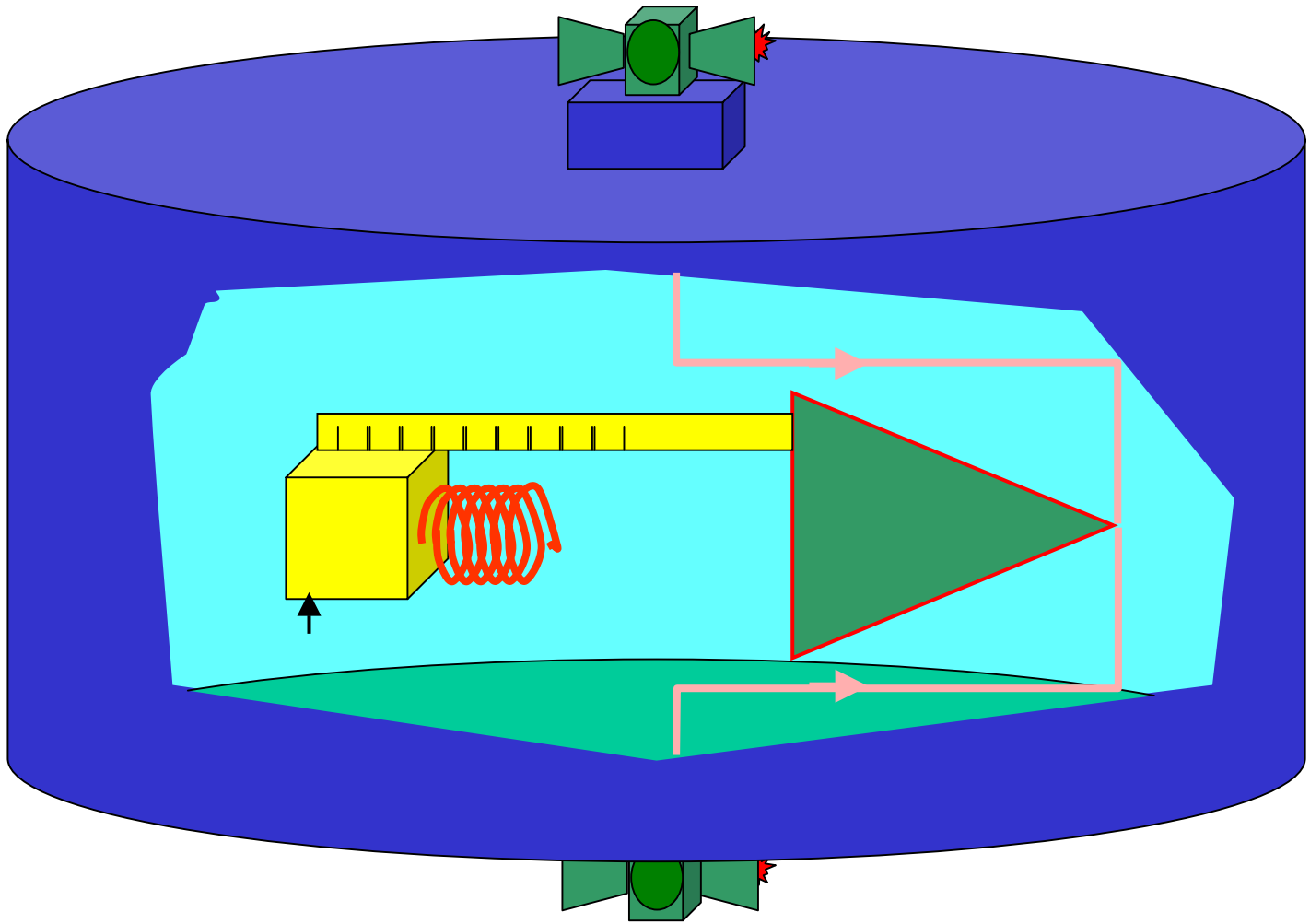


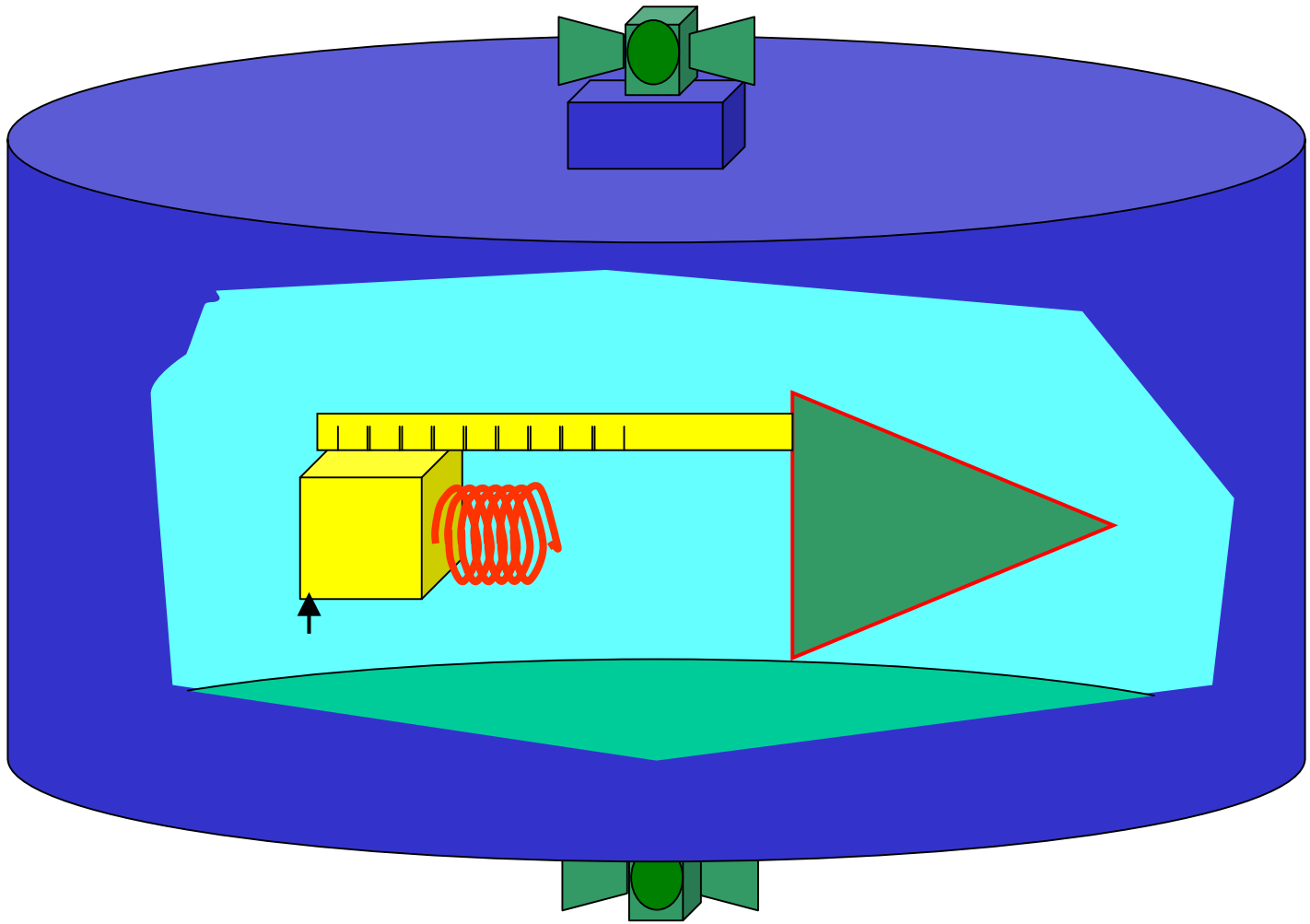












Testing quality of free fall

$\sqrt{S_F}\left(\frac{N}{\sqrt{Hz}}\right)$

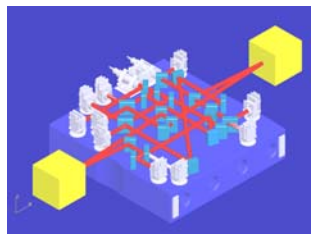
10^{-12}

10^{-13}

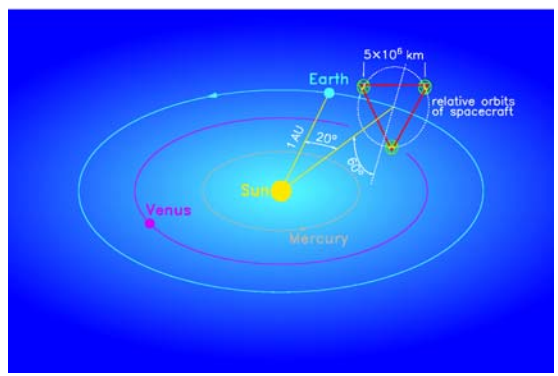
10^{-14}

10^{-15}

Torsion pendulum
(surface disturbances)



LISA PF



LISA

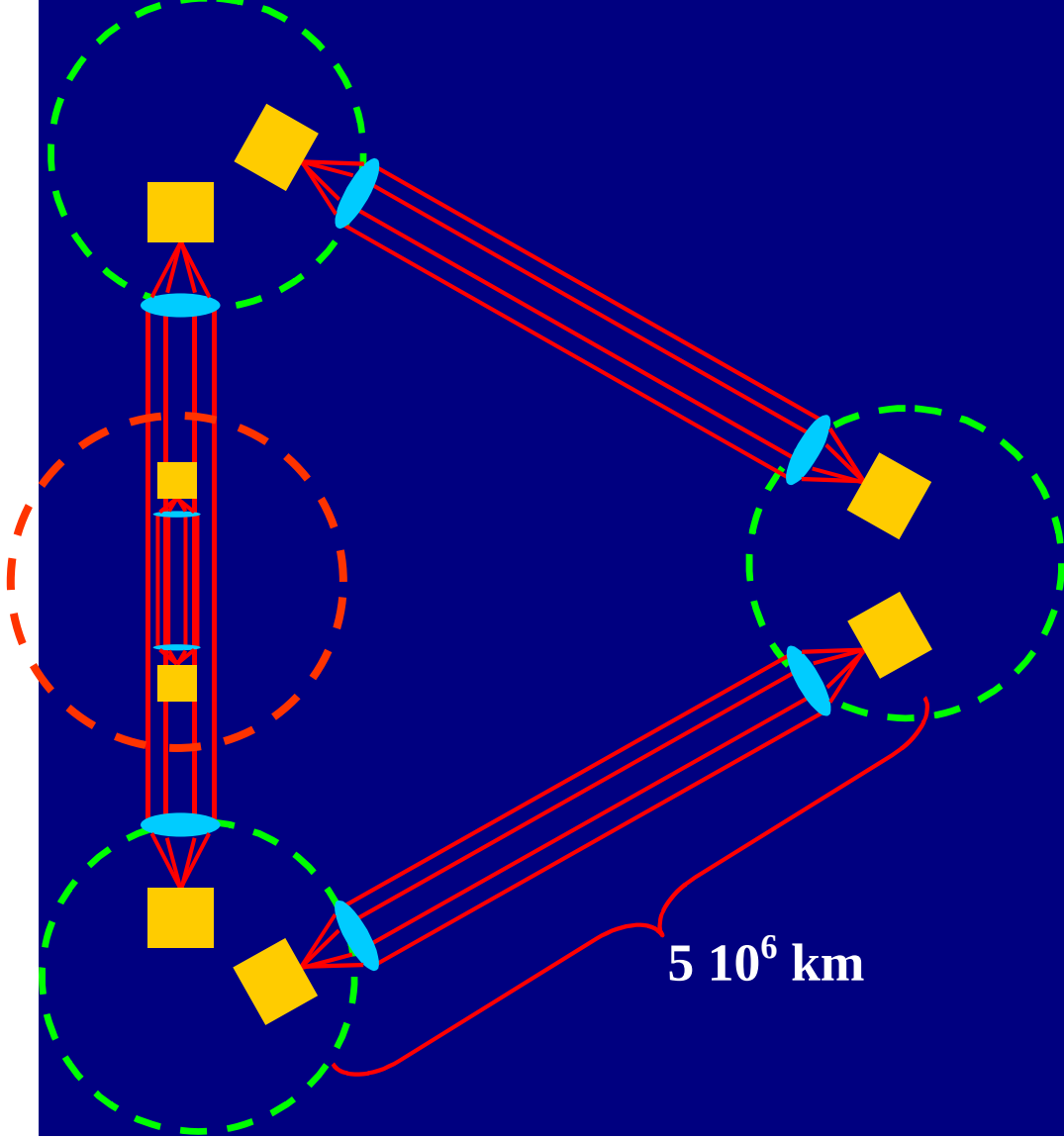
LISA Pathfinder in-flight test:

1) Take 1 LISA's arm

2) Squeeze it to 35 cm

3) Fit into one spacecraft

4) Measure relative acceleration

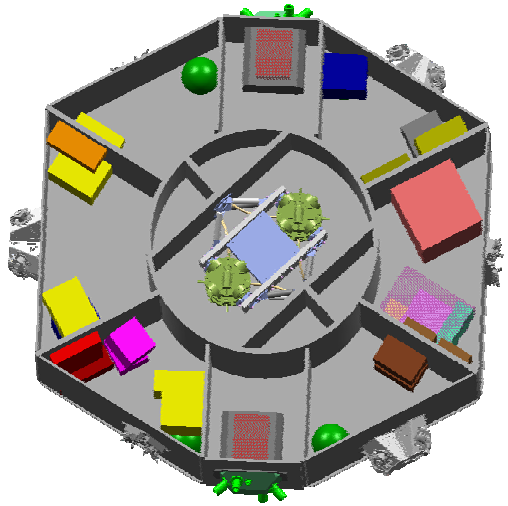


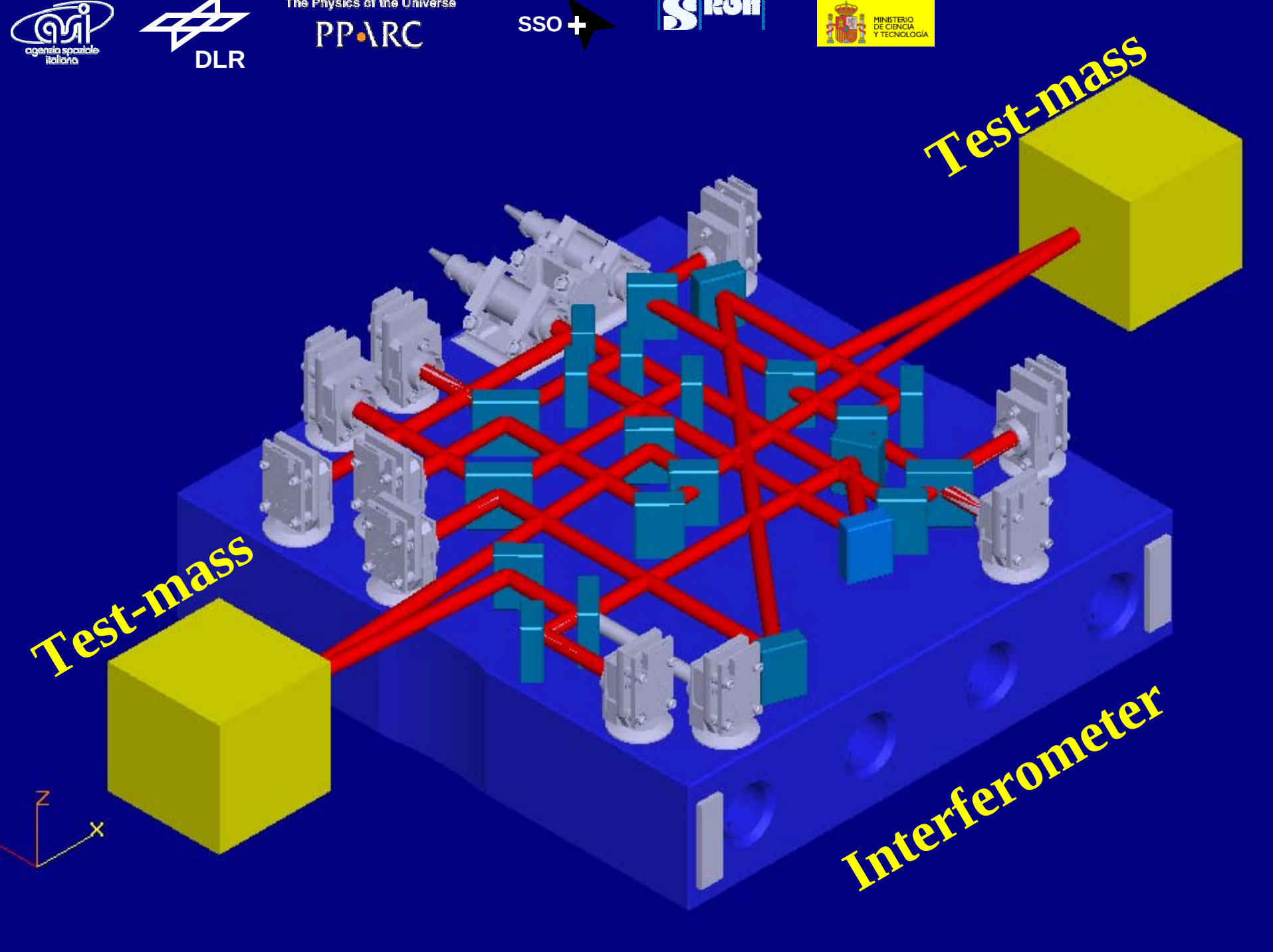
A factor 10 from LISA goals

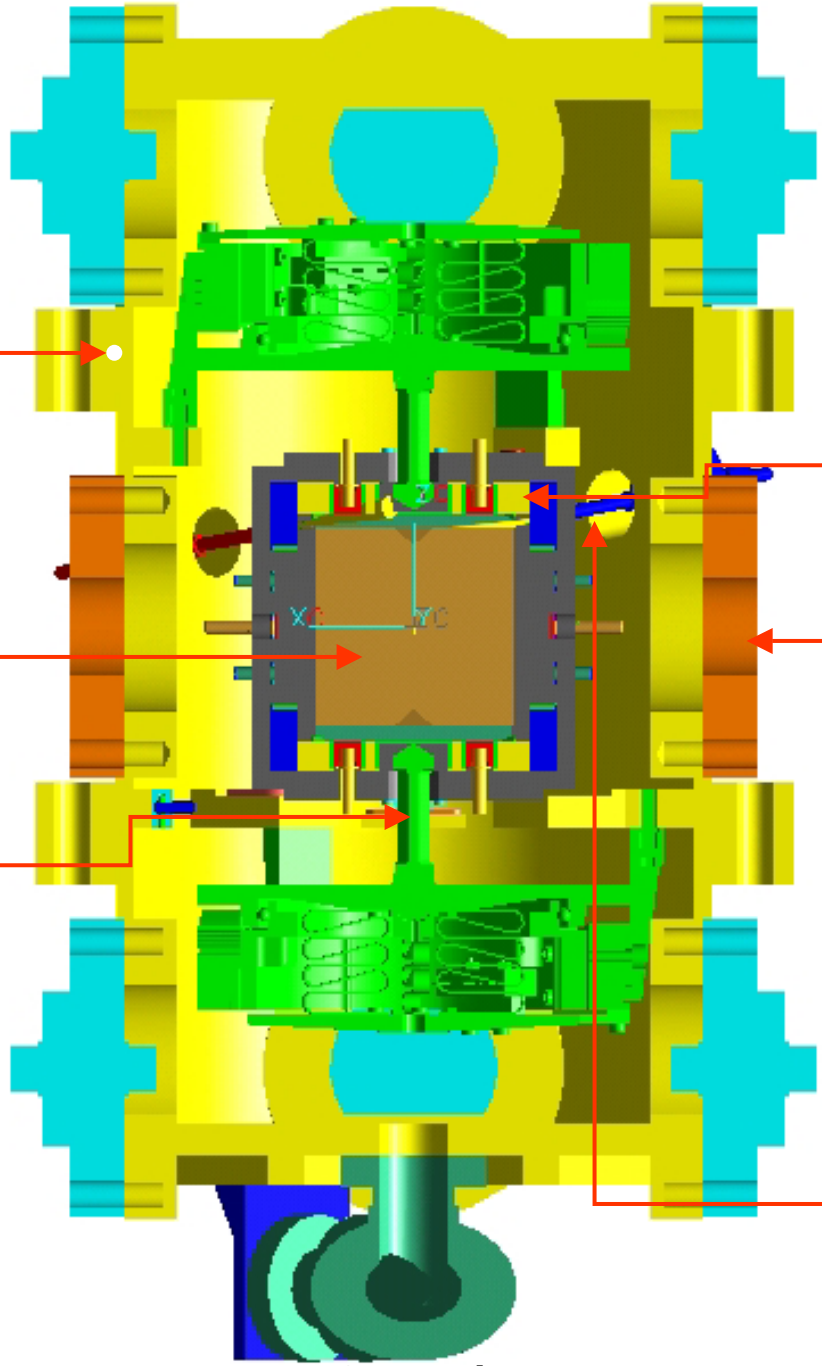
$$\delta a \leq 3 \cdot 10^{-14} \frac{ms^{-2}}{\sqrt{Hz}} \qquad 1\ mHz \leq f \leq 30\ mHz$$

LISA Pathfinder

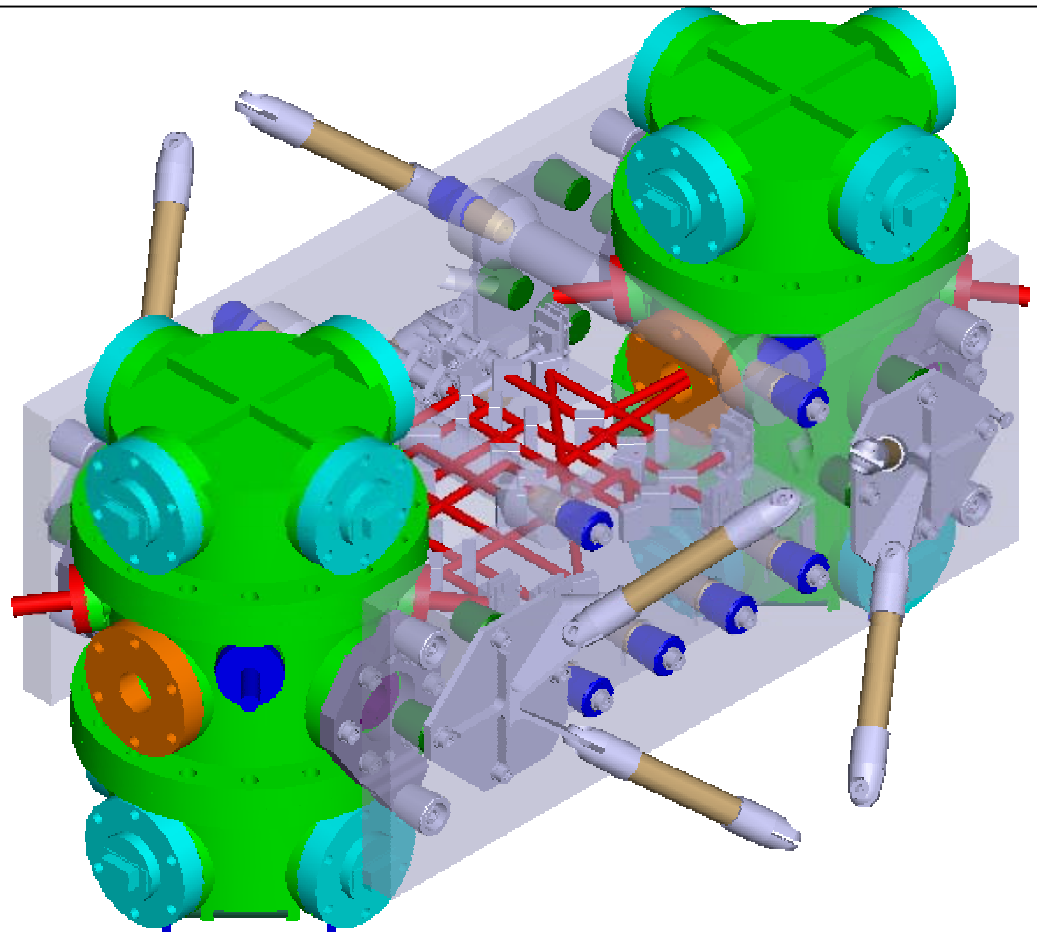
- ESA mission, launch in 2008
- European LTP
  - Inertial Sensor
  - Optical Metrology
  - Drag-free control
  - Phase-measurement
- US DRS
  - Similar to LTP with “coordinated differences” (materials, design, interferometry)
  - Oriented 45º to the LTP to allow for a “LISA simulation” during combined operation
- Thruster systems
  - FEEPS, colloidal thrusters, cold gas, hydrazine



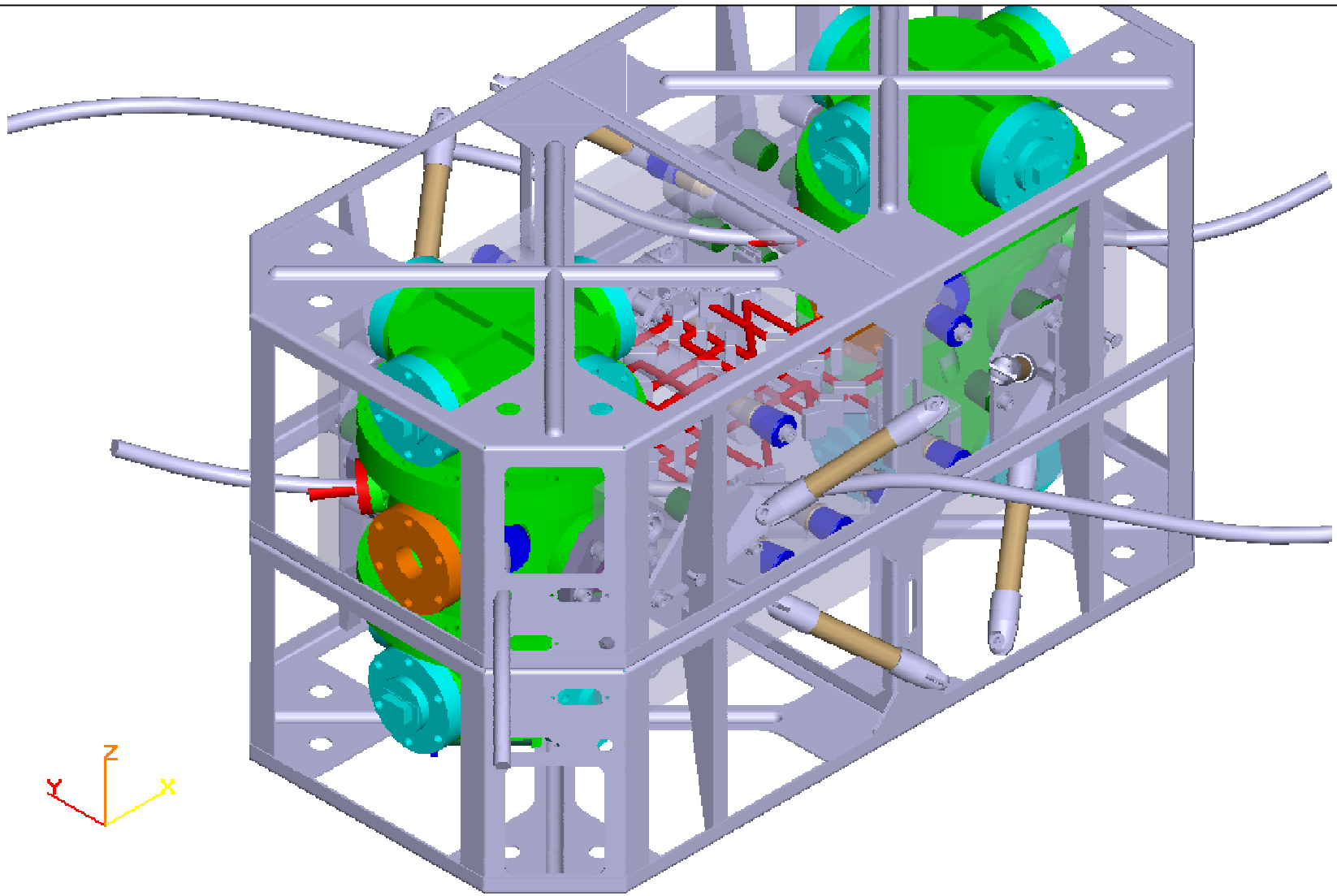

Test-mass
Test-mass
Interferometer
Z
X


Vacuum enclosure
Test-mass
Caging Mechanism
Electrode Housing
Optical Window
UV Optical Fibres for Discharging

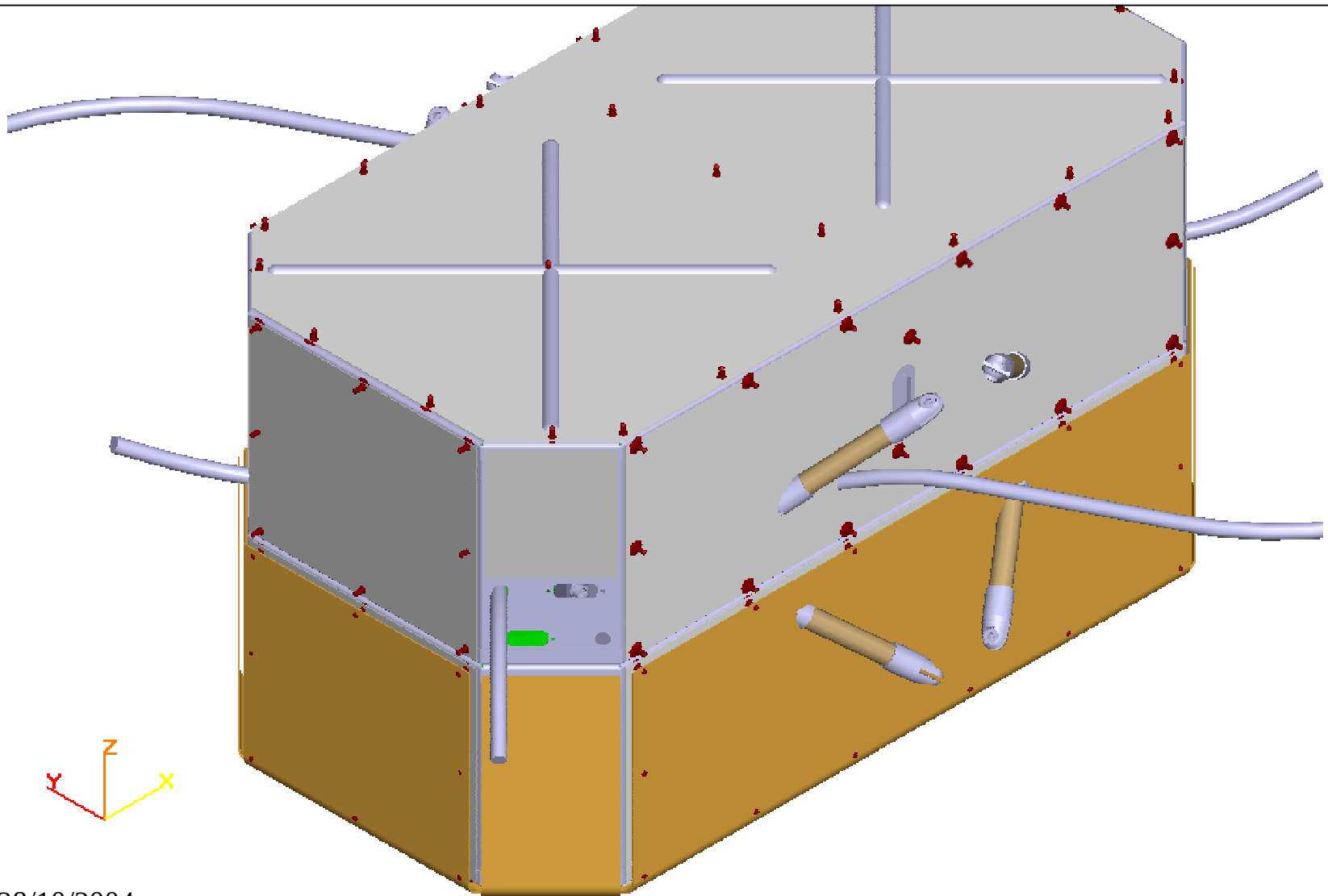
The LTP



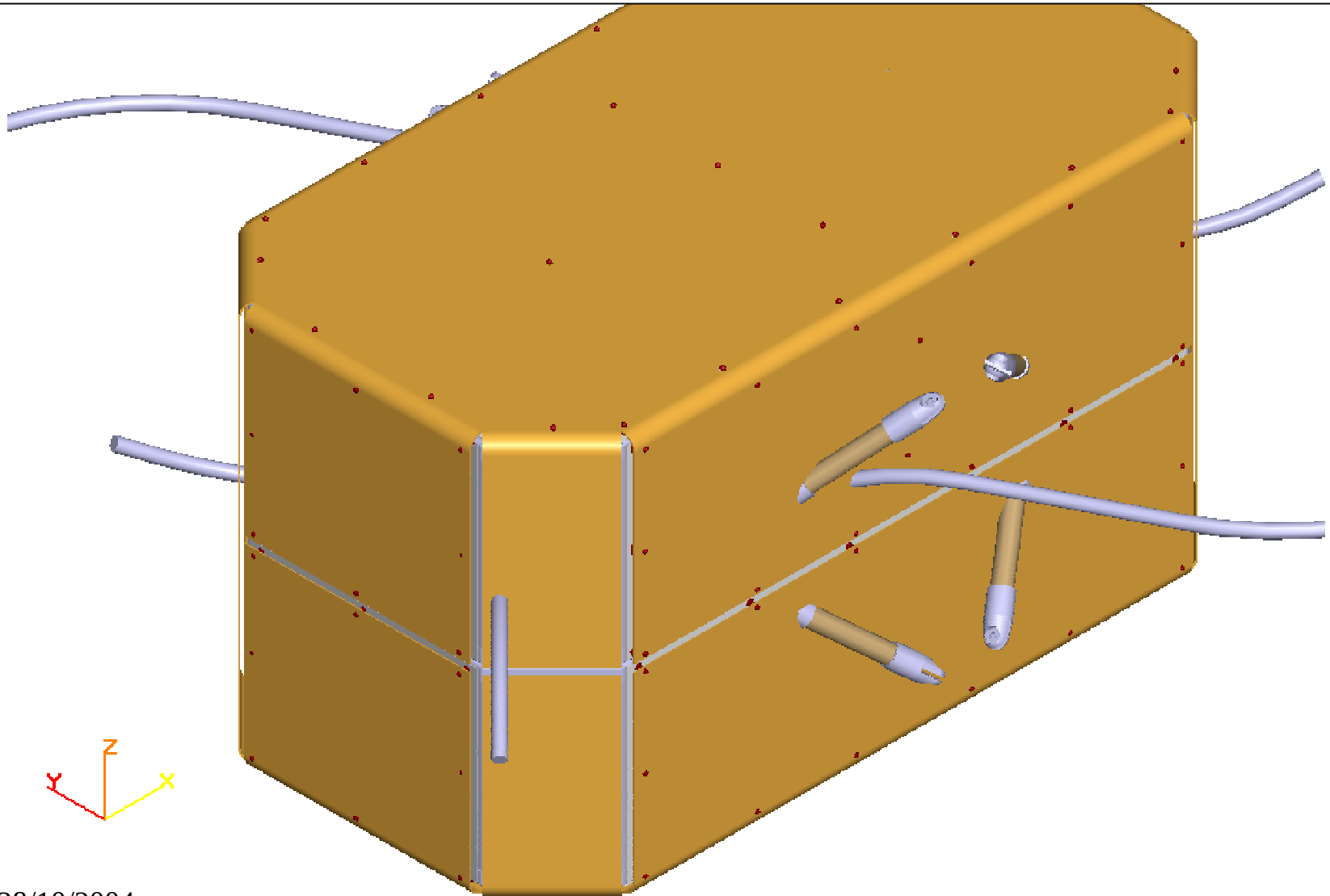
The LTP

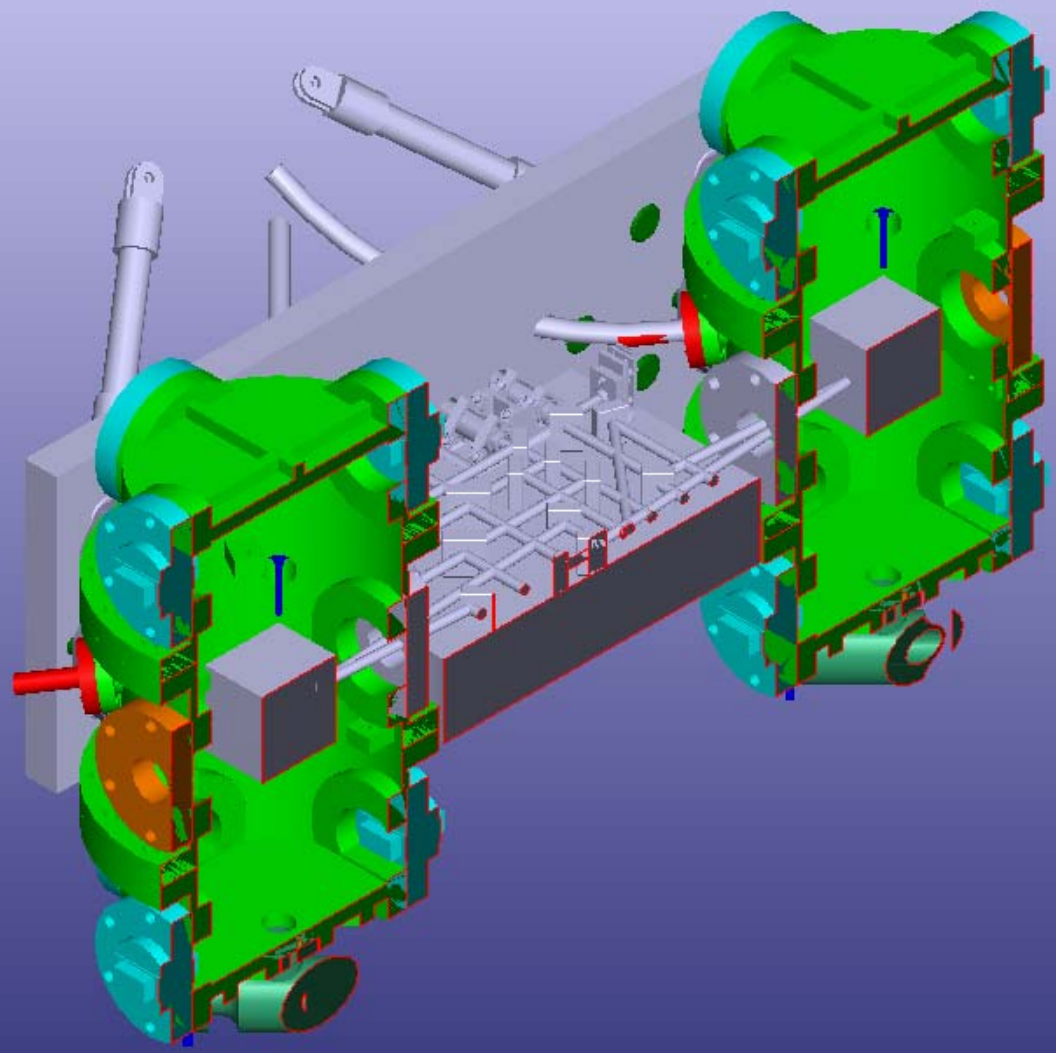


The LTP



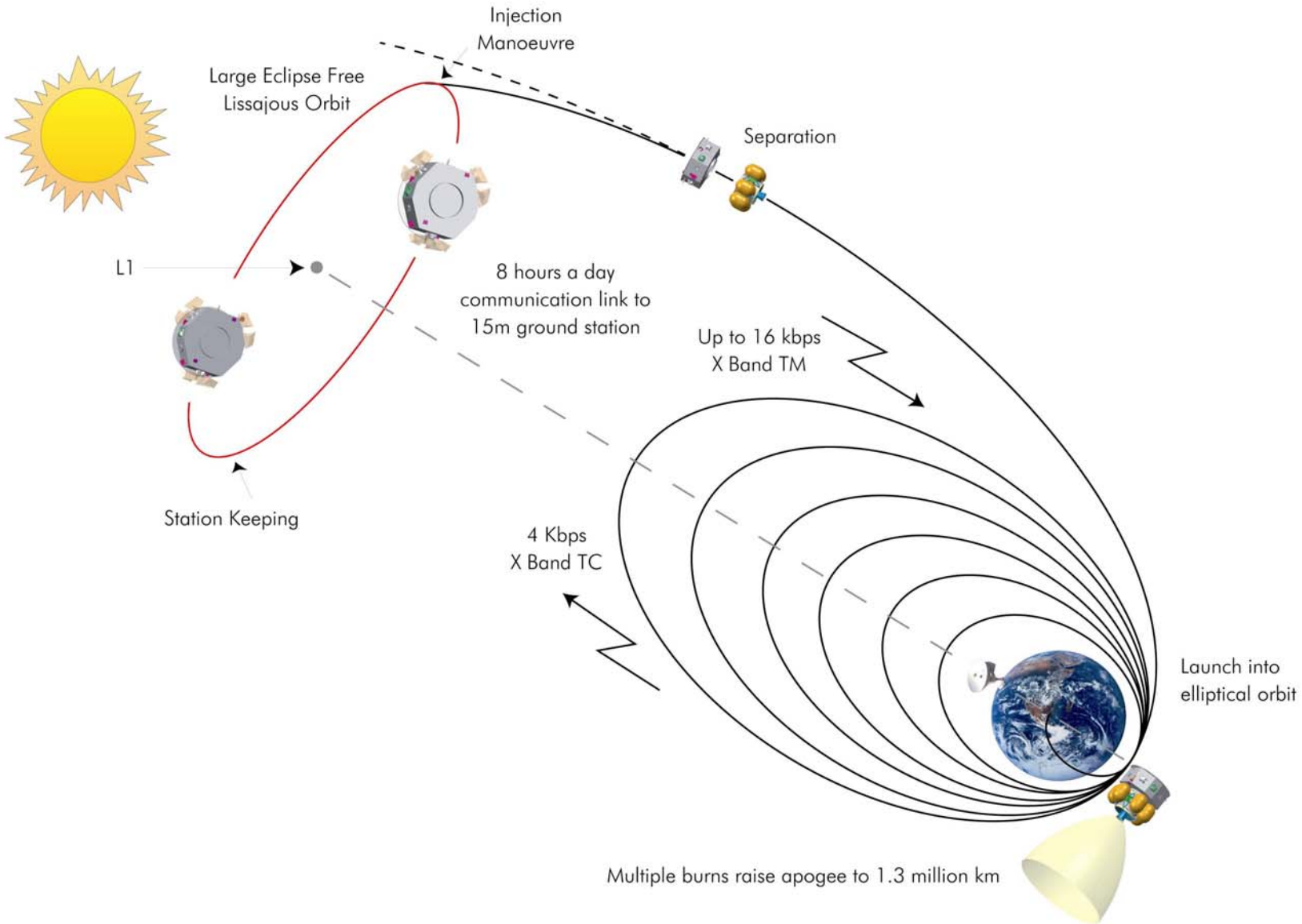
The LTP




Z
Y
X

National Contributions to LPF

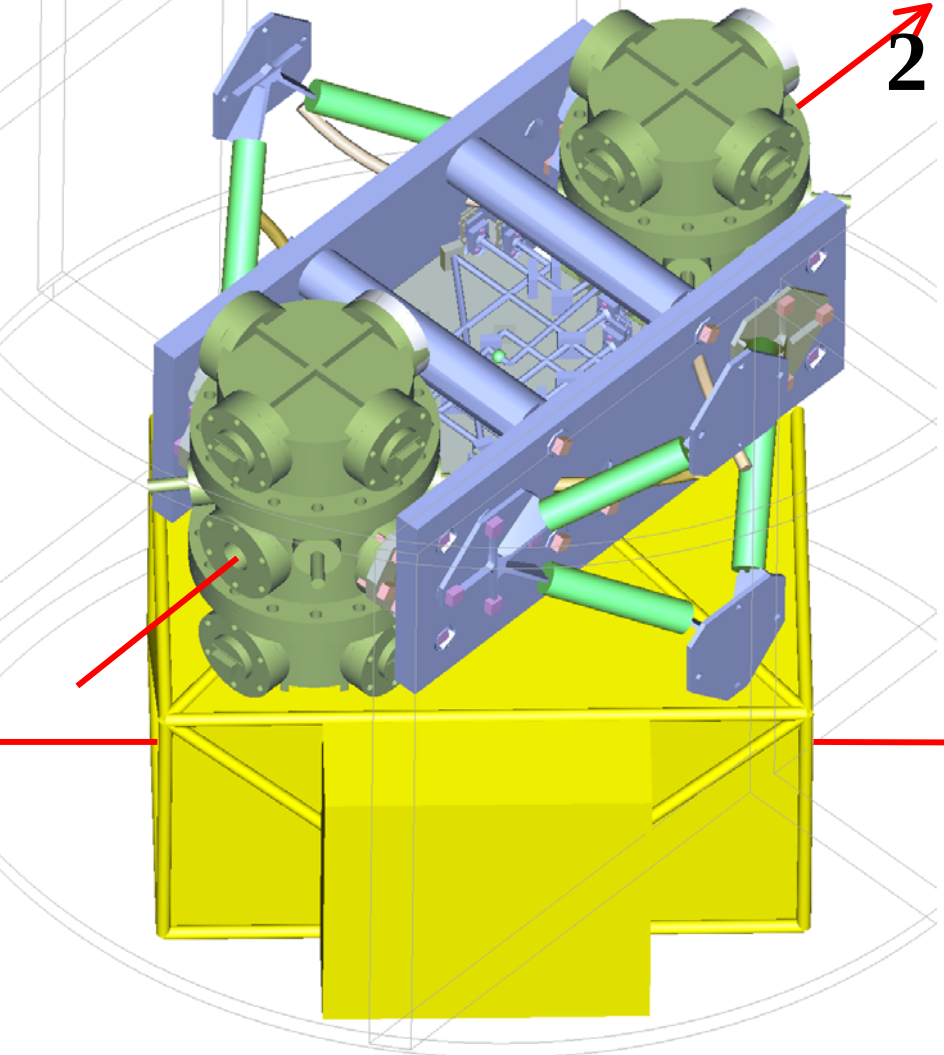
- Industrial Architect and System Engineering
  - Germany (Prime), Italy (Support)
- Inertial Sensor
  - Italy (Design, AIVT), Switzerland (Front End Electronics), UK (Charge Control), Open (Caging Mechanism)
- Laser Assembly (Laser, AOM bench, stabilization algorithms)
  - Germany (Design, Laser, AIVT),
  - France (Modulator unit incl. AOMs)
- Interferometry and Optical Bench
  - Germany (Design and final AIVT), UK (Optics and OB pre-integration)
- Phasemeter Front-End (Diodes, ADs, FPGAs, Algorithms)
  - UK (FM and EM), Germany (Concept and Breadboard)
- Data Management Unit (Processor, PM back end, environ monitor)
  - Spain

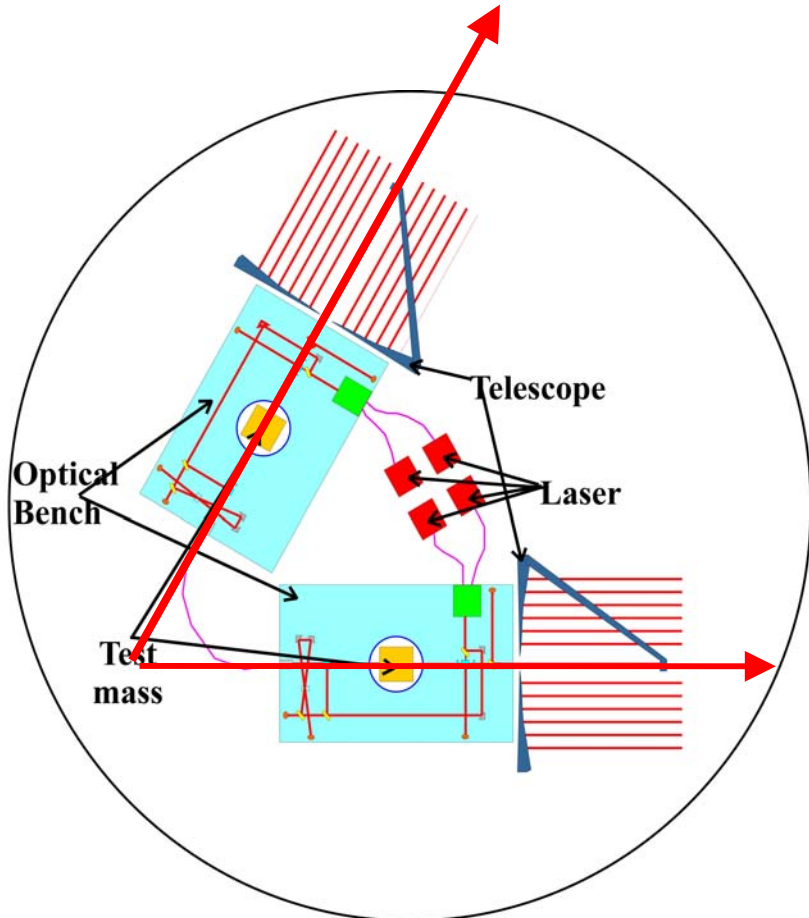

Injection
Manoeuvre
Large Eclipse Free
Lissajous Orbit
Separation
L1
8 hours a day
communication link to
15m ground station
Up to 16 kbps
X Band TM
Station Keeping
4 Kbps
X Band TC
Launch into
elliptical orbit
Multiple burns raise apogee to 1.3 million km

LTP/ST-7 joint operation

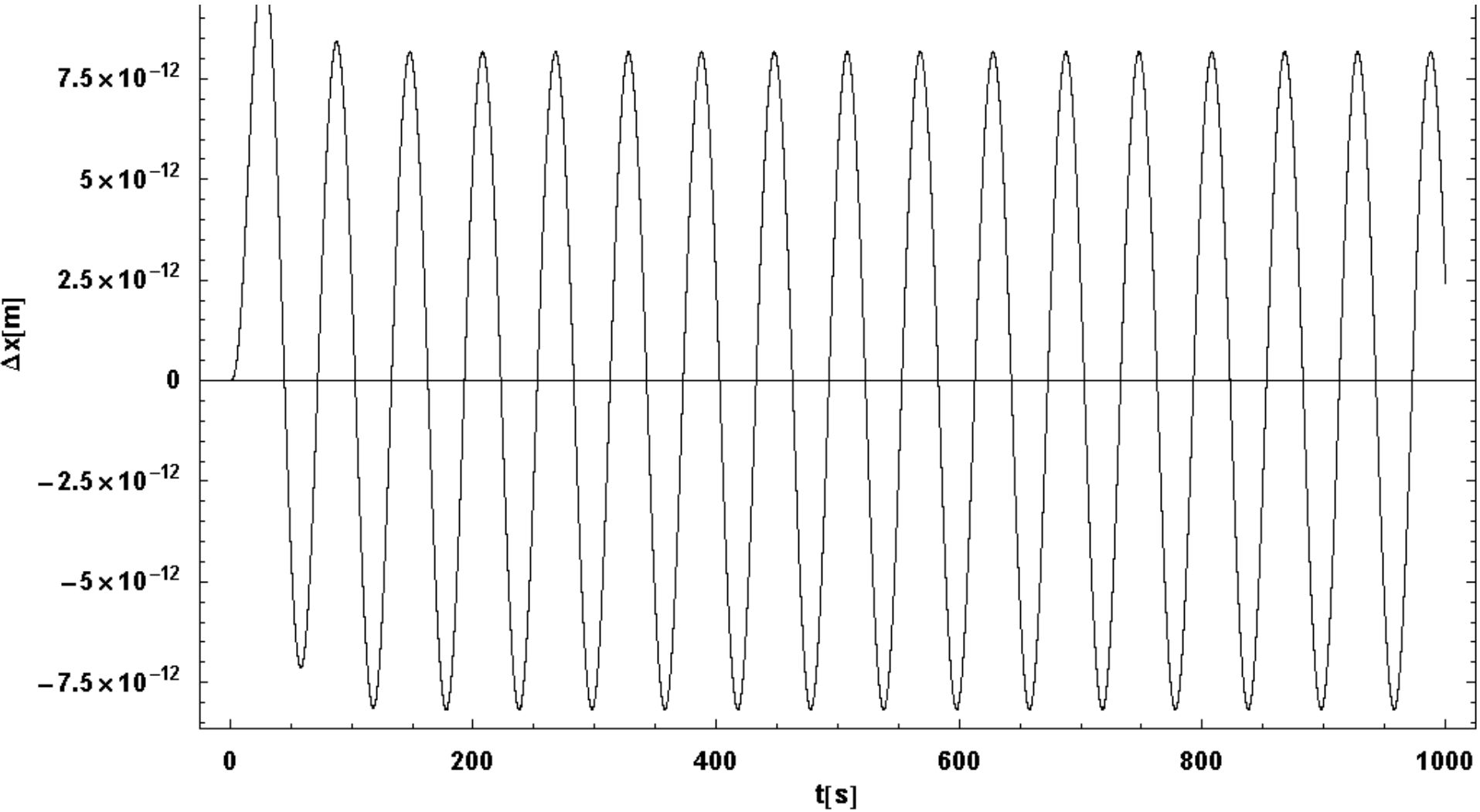
2 masses control as in LISA

Disturbance correlation





Gravitational calibration (big G at 1 mo km?)



200 μm p-p displacement of ST-7 test-mass: signal at LTP output. SNR>1000 in a few hours