DRAQANE: Drag-compensation Residual-atmosphere Air-breathing Quantum Array Navigation Experiment

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Introduction & Objectives

Satellite constellations uphold modern society: Positioning, navigation and timing services are crucial in many industries, from transportation and finance to cellular networks and power grids. Yet, today's Global Navigation Satellite Systems are vulnerable to jamming and spoofing. Very Low Earth Orbit (VLEO) satellites offer significant benefits: The signals are about ten times stronger, the fast motion shortens the convergence time, and the large Doppler-shift makes spoofing detectable. Additionally, increased accuracy in all aspects can be achieved with quantum clock synchronization between satellites in a navigation fleet. The Drag-compensation Residual-atmosphere Air-breathing Quantum Array Navigation Experiment (DRAQANE) combines these advantages while conquering the unforgiving environment of VLEO. The primary mission objectives are:

1. to validate inter-satellite quantum clock synchronisation in VLEO and

2. to provide nanosecond-level timing to ground navigation receivers.

The secondary objective is the in-situ comparison of different ABEP intakes at different altitudes.

Mission Scenario

The DRAQANE constellation is planned to launch before the end of 2030 and will consist of 3 satellites. It will operate for at least one year. At the beginning of the mission the three satellites will fly in a dawn-dusk sun-synchronous orbit with 10° (about 1170 km) in-plane separation. The mission timeline can be seen in the diagram below.
Each of the three DRAQANE satellites carries a payload that synchronises their on-board clocks via two-way quantum time transfer using entangled photon pairs. The same photons generate QKD keys that encrypt the timing and orbit data exchanged over optical inter-satellite links, and each satellite broadcasts the synchronised time and orbit to users as an L-band navigation signal.

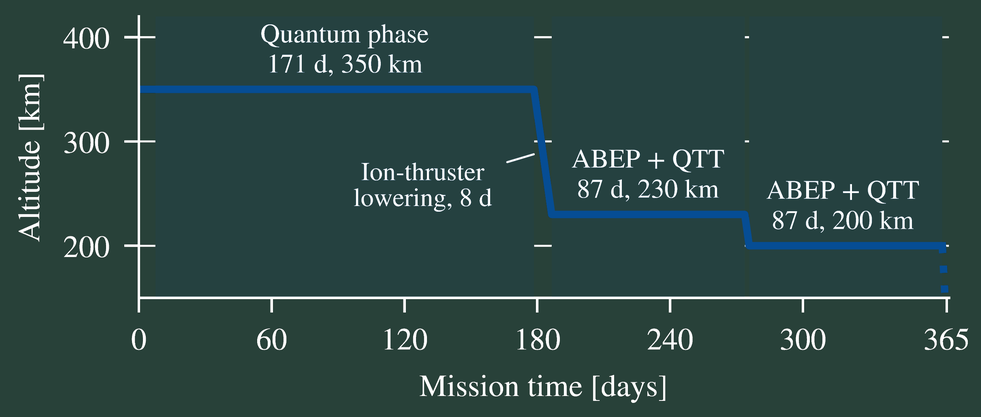


Figure 1: Mission profile over one year of operations starting at 350 km followed by ABEP phases at 230 km and 200 km.

Scientific Payload

Compared with 20 ns to 50 ns for GPS-based synchronisation and 5 ns to 10 ns for Galileo-based synchronisation, the 30 ps precision reduces the corresponding clock term from 6 m to 15 m for GPS and 1.5 m to 3 m for Galileo to 9 mm, resulting in a navigation error of 0.69 m, now limited purely by the orbit determination error.

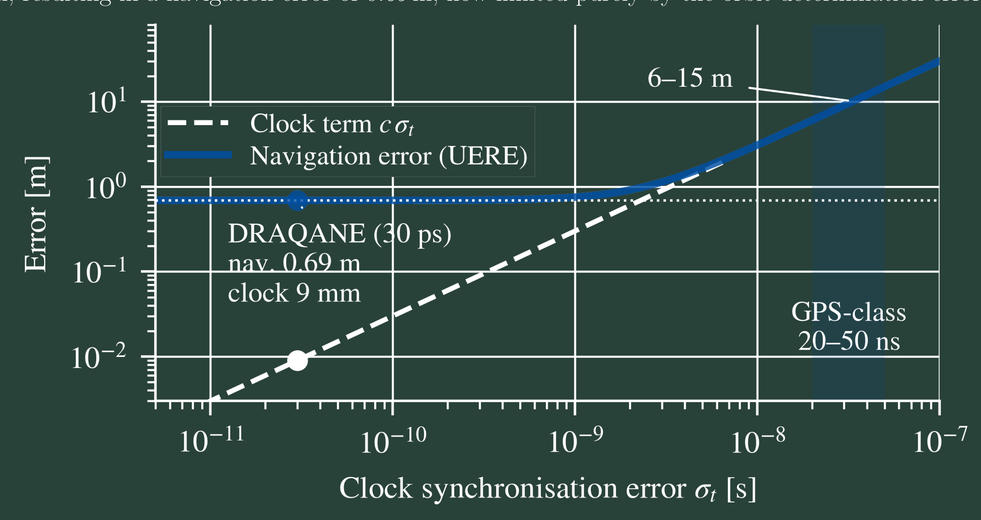


Figure 2: Clock and navigation error as a function of clock synchronisation error.

Propulsion System

The propulsion architecture pairs a flight-proven QinetiQ T5 ion thruster for VLEO station-keeping with a dedicated Atmosphere-Breathing Electric Propulsion (ABEP) payload. The ABEP system collects and ionizes residual thermospheric gas through an intake and RF inductive plasma thruster to demonstrate propellant-free drag compensation.
Three distinct intake designs are evaluated across the formation. Diagnostic instruments include an Ion and Neutral Mass Spectrometer (INMS), Quartz Crystal Microbalances (QCM) for erosion monitoring, and FIPEX sensors for atomic oxygen density.

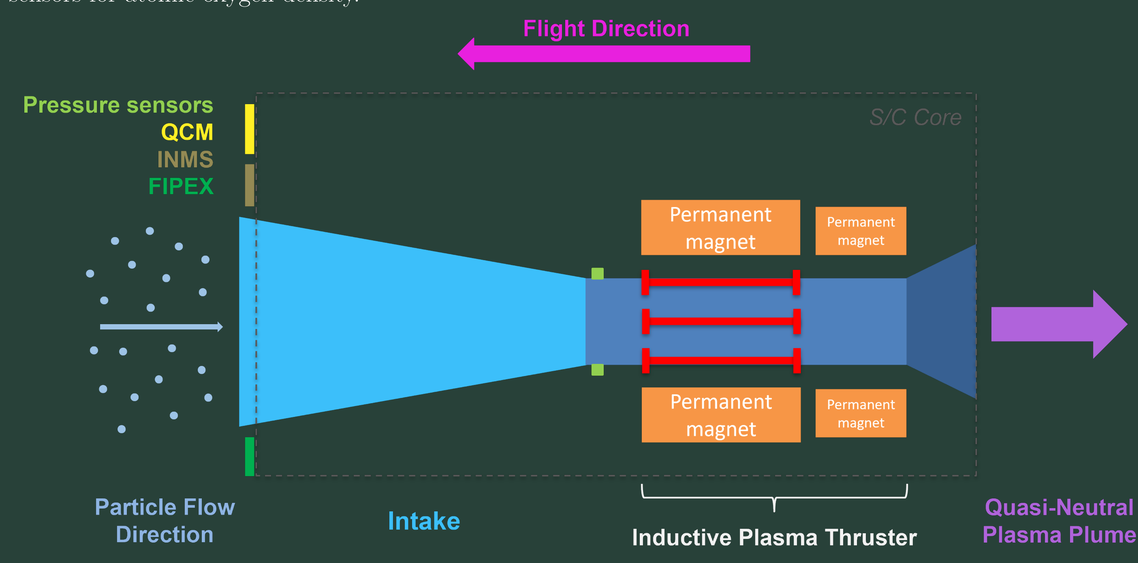


Figure 3: ABEP System Architecture: Intake geometry, RF discharge chamber, and sensor diagnostic suite.

System Budgets (Mass, Power, Cost)

Detailed resource breakdown per satellite (including 5–15% item contingency and 15% overall system margin):

Subsystem	Mass [kg]	Power [W]	FM Cost [M$]
STR & MCH & TCS	179.2	104.5	7.84
ADCS + Main Propulsion	86.8	2088.70	21.71
Electrical Power	46.3	10	2.90
Payload (incl. ABEP)	62.1	711.7	2.23
Communications	3.0	30.8	2.92
Support	-	-	29.51
Per Satellite	**377.3 kg**	**2945.7**	**67.11**

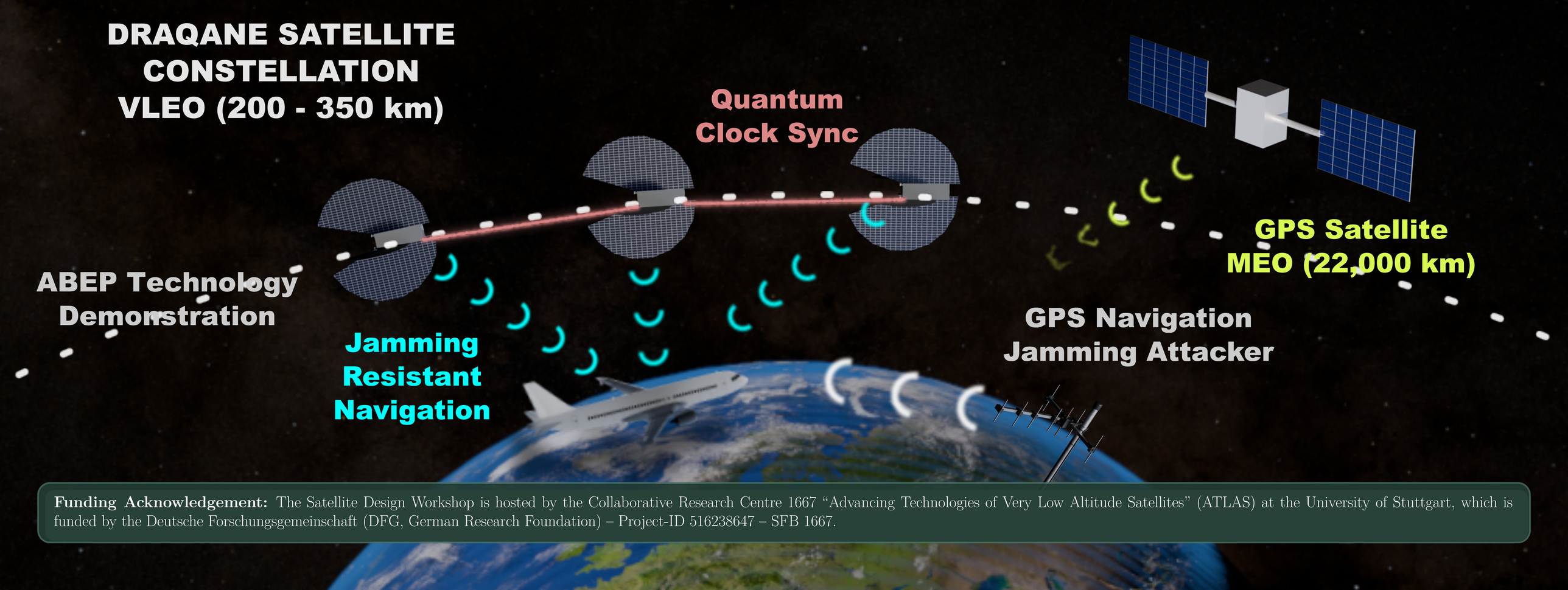
Power Budget: Orbit-average worst-case power consumption is 1.88 kW with both main propulsion and ABEP firing during the eclipse phase (37 min max).

Program Cost: Total program cost is estimated at **$643.76M**, covering development, manufacturing, and full mission operations over one year.

Conclusions & Outlook

DRAQANE demonstrates quantum-secure clock synchronization in Very Low Earth Orbit (VLEO), turning high-precision timing into a resilient navigation service for ground users while evaluating atmosphere-breathing propulsion in flight:

- **Quantum Timing:** Validates sub-30 ps inter-satellite time transfer, lowering the navigation error floor down to 0.69 m.
- **VLEO Resilience:** Exploits 10× stronger signal strength and large Doppler shifts to mitigate GNSS jamming and spoofing risks.
- **ABEP Maturation:** Provides in-situ comparative data across three intake geometries down to 200 km altitude, paving the way for sustainable long-life VLEO operational fleets.



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