On the Automation, Optimization, and In-Orbit Validation of Intelligent Satellite Constellation Operations

35th Annual Small Satellite Conference

VIDEO

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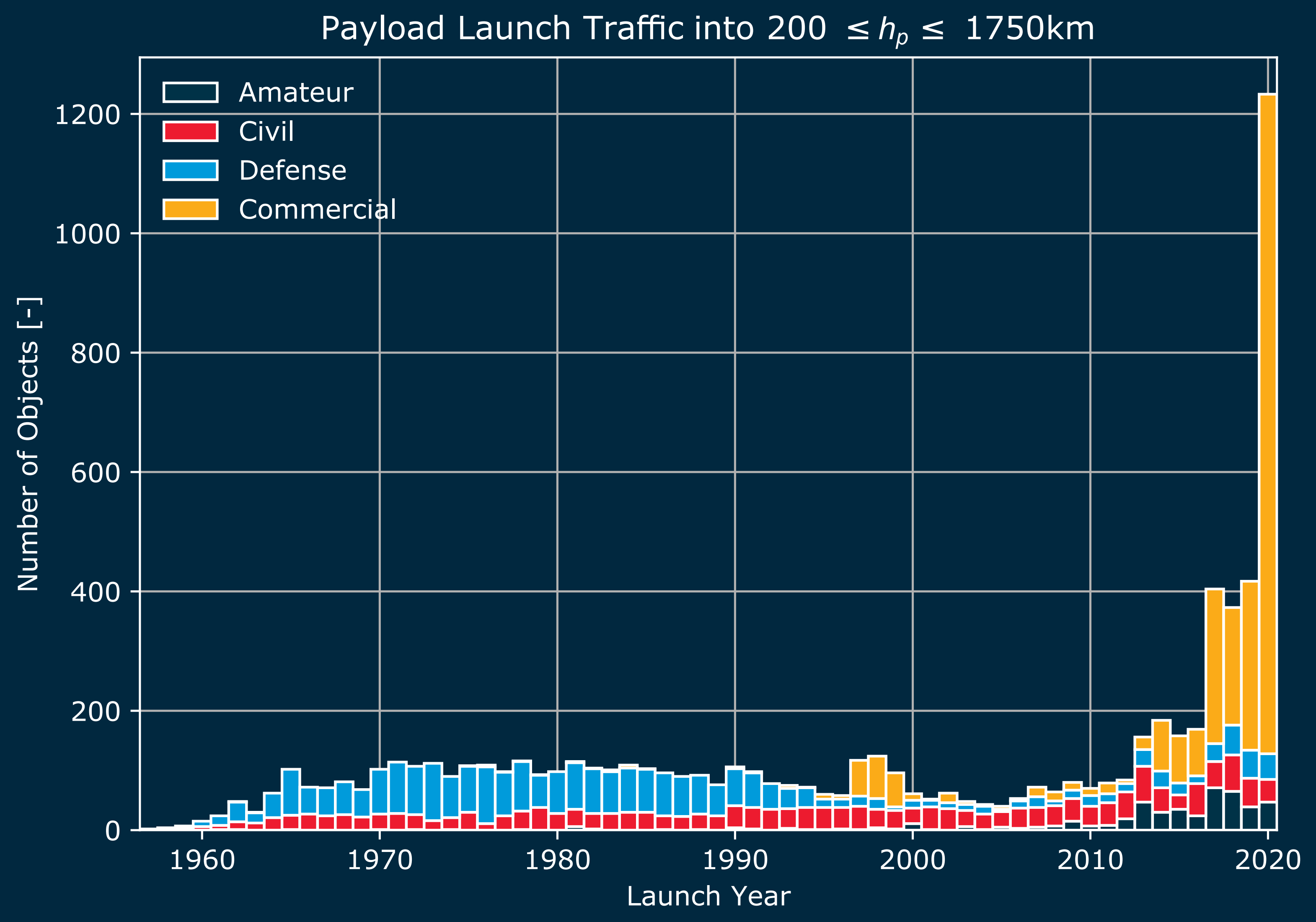
This presentation is available as a video:
https://leopowver.space/publications/2021-smallsat



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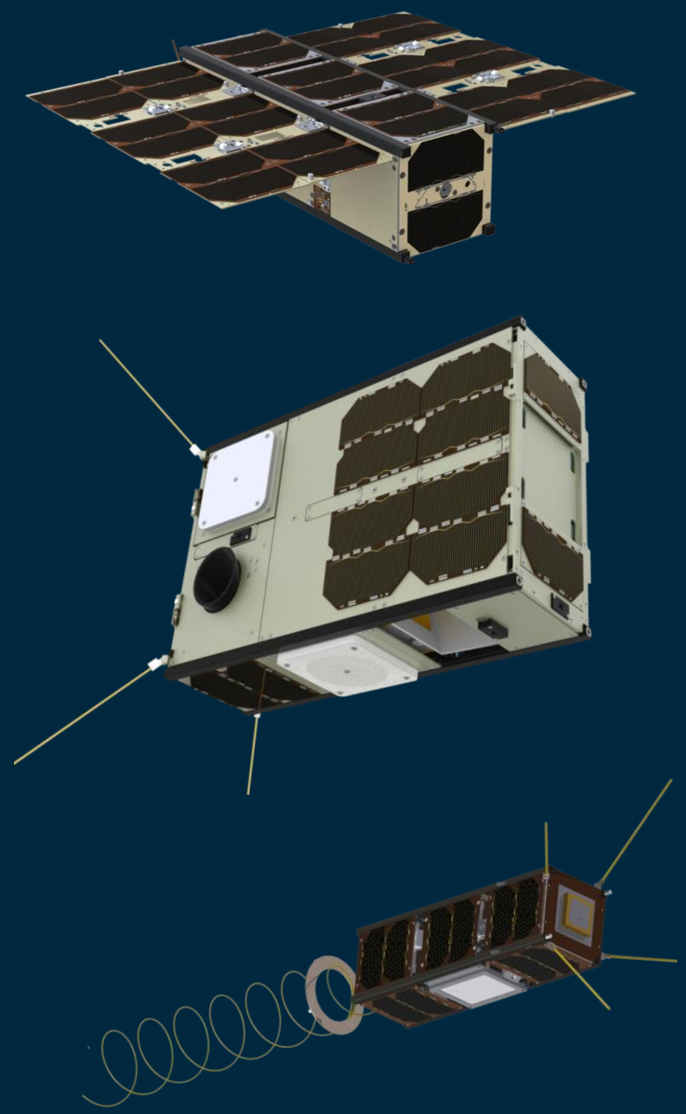
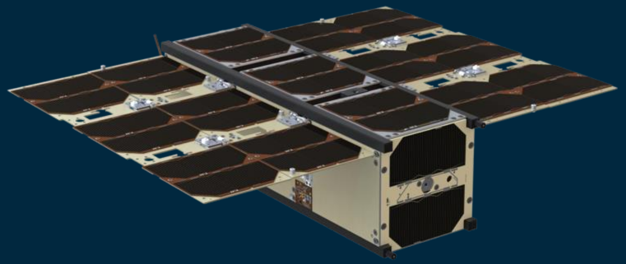
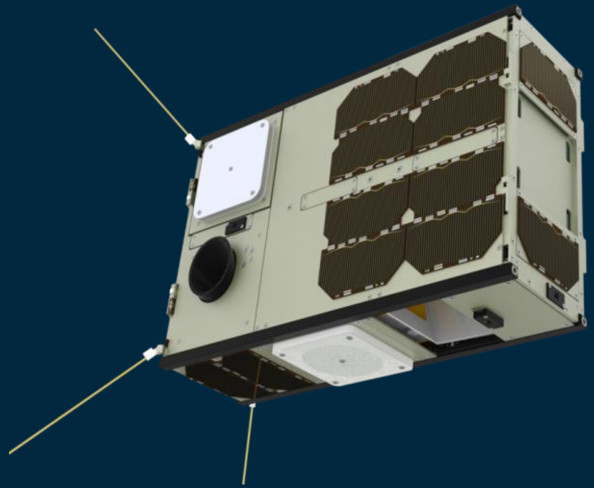
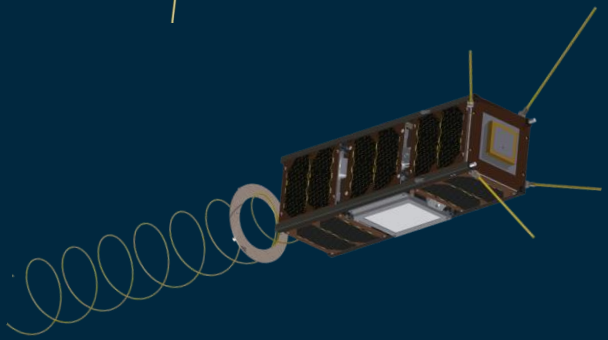


- **Automating the operation** of satellite constellations is very demanding.
- We develop methods to **optimize resource usage** with respect to **data delivery** and **battery utilization**.
- We combine the **best of two worlds**:
  - novel **research** in Computer Science (optimal algorithms, self-improving learning, …)
  - experienced market leader in the **industry**: GOMSPACE

GOMSPACE

SUBSYSTEMS

- 80% IN HOUSE
- 20% TRUSTED PARTNERS
- ADAPTED TO MISSIONS

RADIO PAYLOADS

- SOFTWARE DEFINED RADIO
- ANTENNAS 0-40 GHz
- AIS & ADS-B TRACKING
- COMMUNICATION

PLATFORMS

- SIZE: 1-64U
- FLEXIBLE CONFIGURATIONS
- INTER-SATELLITE LINKING
- ACTIVE STATION KEEPING

CONSTELLATION SERVICES

- SATELLITE OPERATIONS
- NETWORK MANAGEMENT
- DATA DISTRIBUTION

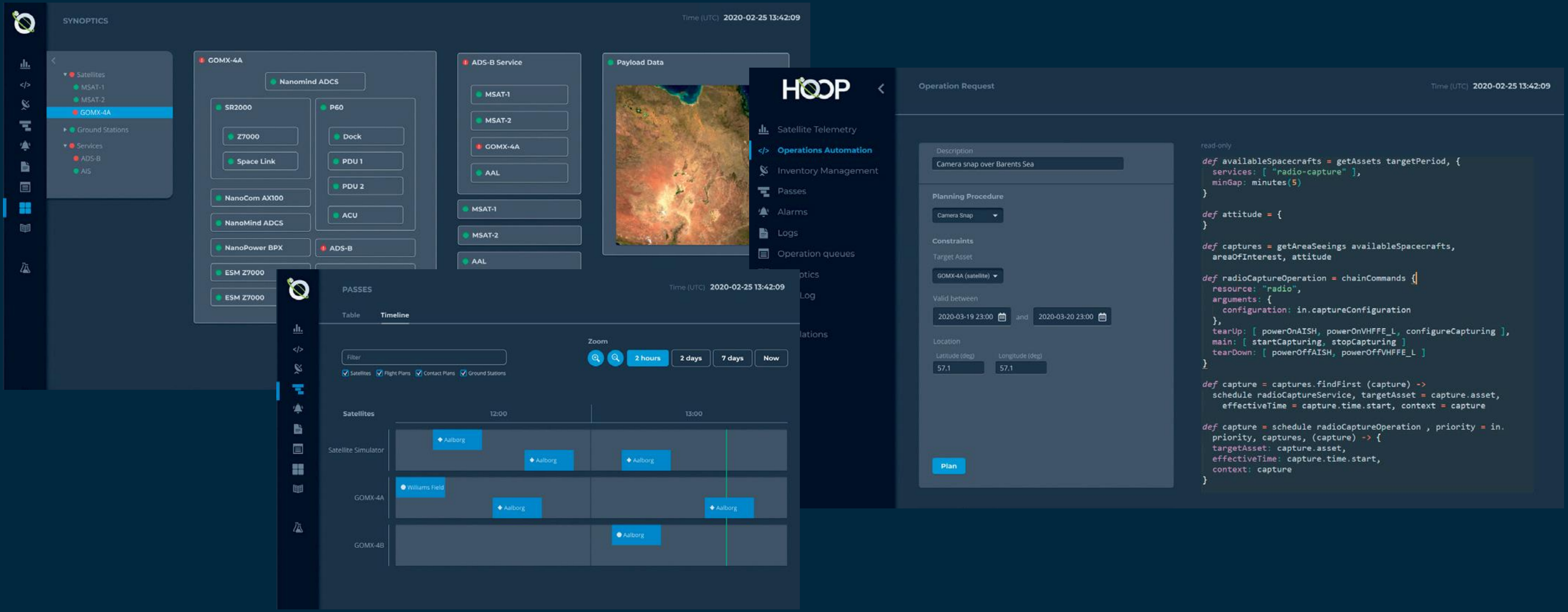
SUPPORT ELEMENTS

- LAUNCH PROCUREMENT
- REGULATORY AFFAIRS
- INSURANCE

"We help teams across the globe achieve their goals in space."

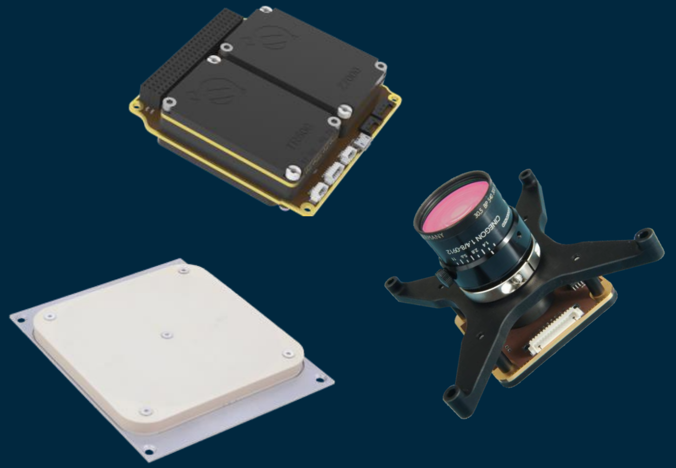
GOMSPACE Hands-off Operations Platform

HOOP
BY GOMSPACE

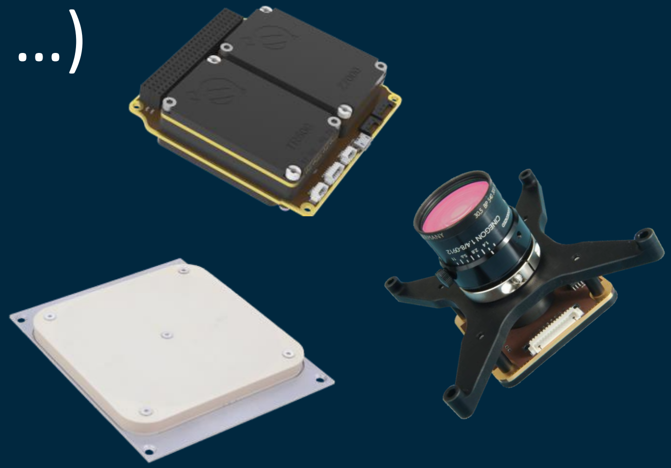



GOMSPACE

- two 6U nanosatellites: GOMX-4A and GOMX-4B
- launched into LEO (500 km SSO) in February 2018
- innovative building blocks for larger constellations
  - Inter-Satellite Link (ISL) up to 4500 km
  - station keeping by propulsive maneuvers in GOMX-4B

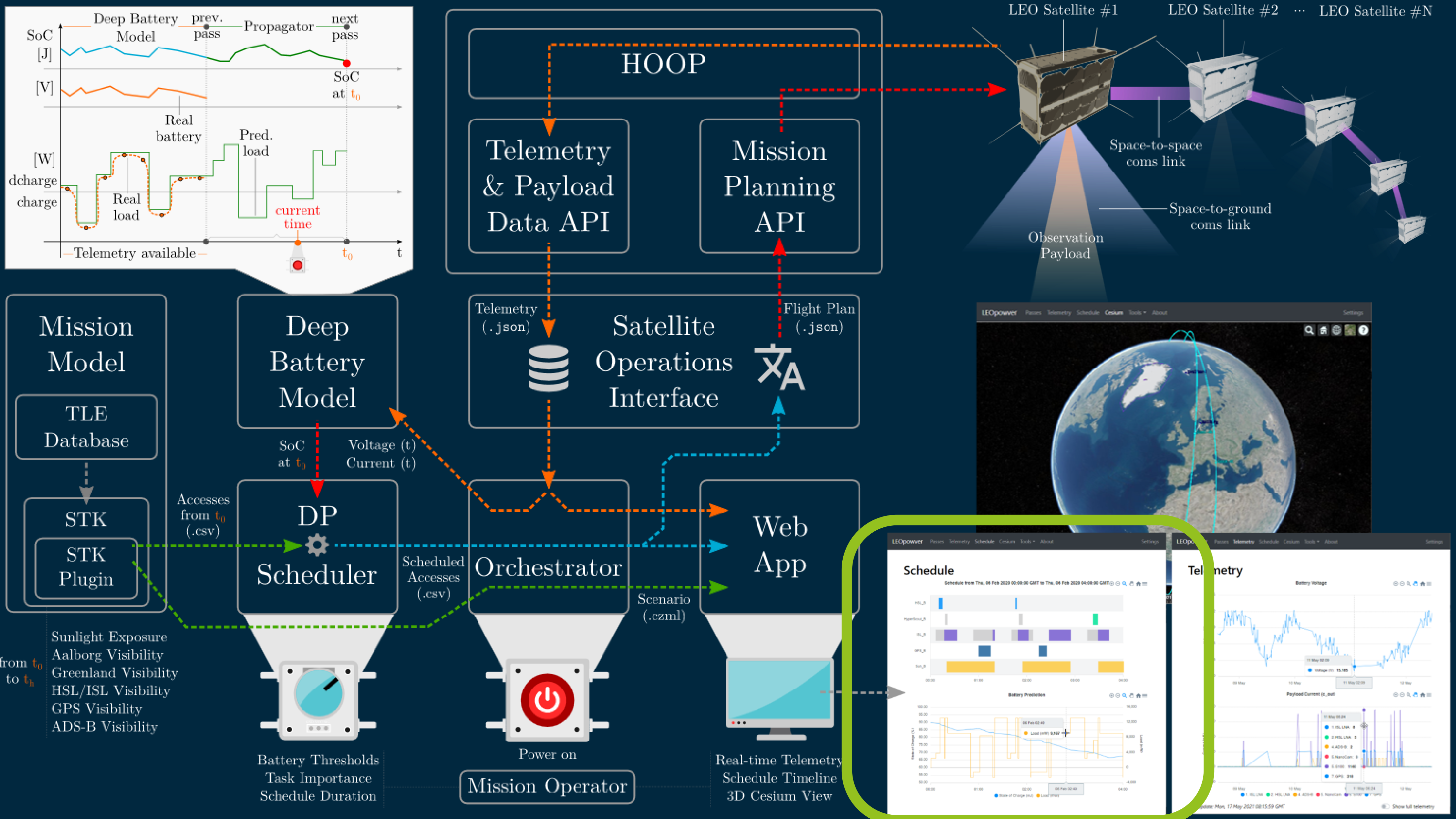


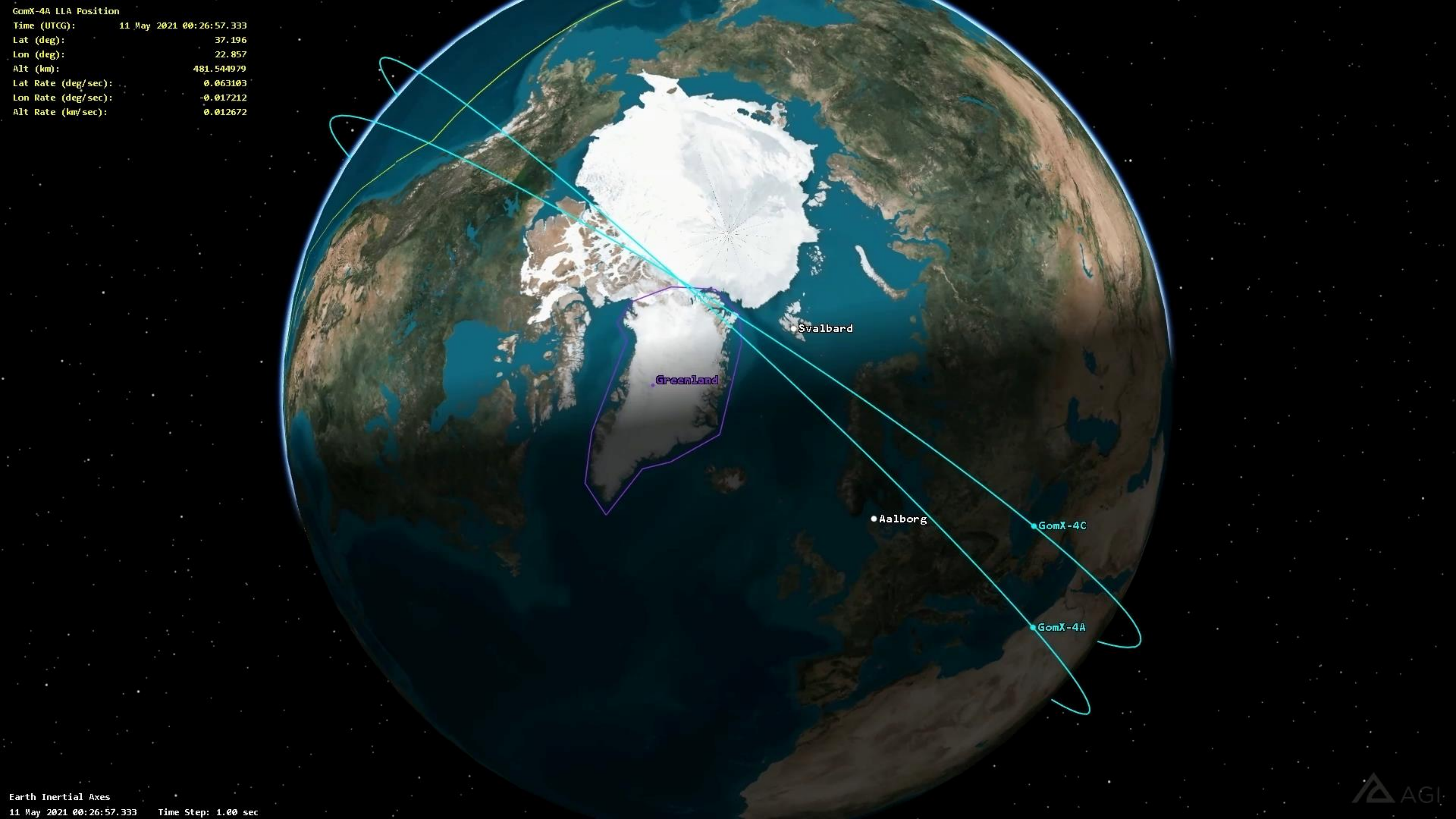
- can perform many activities (ISL/HSL, Camera, ADS-B, …)
- but limited by on-board battery



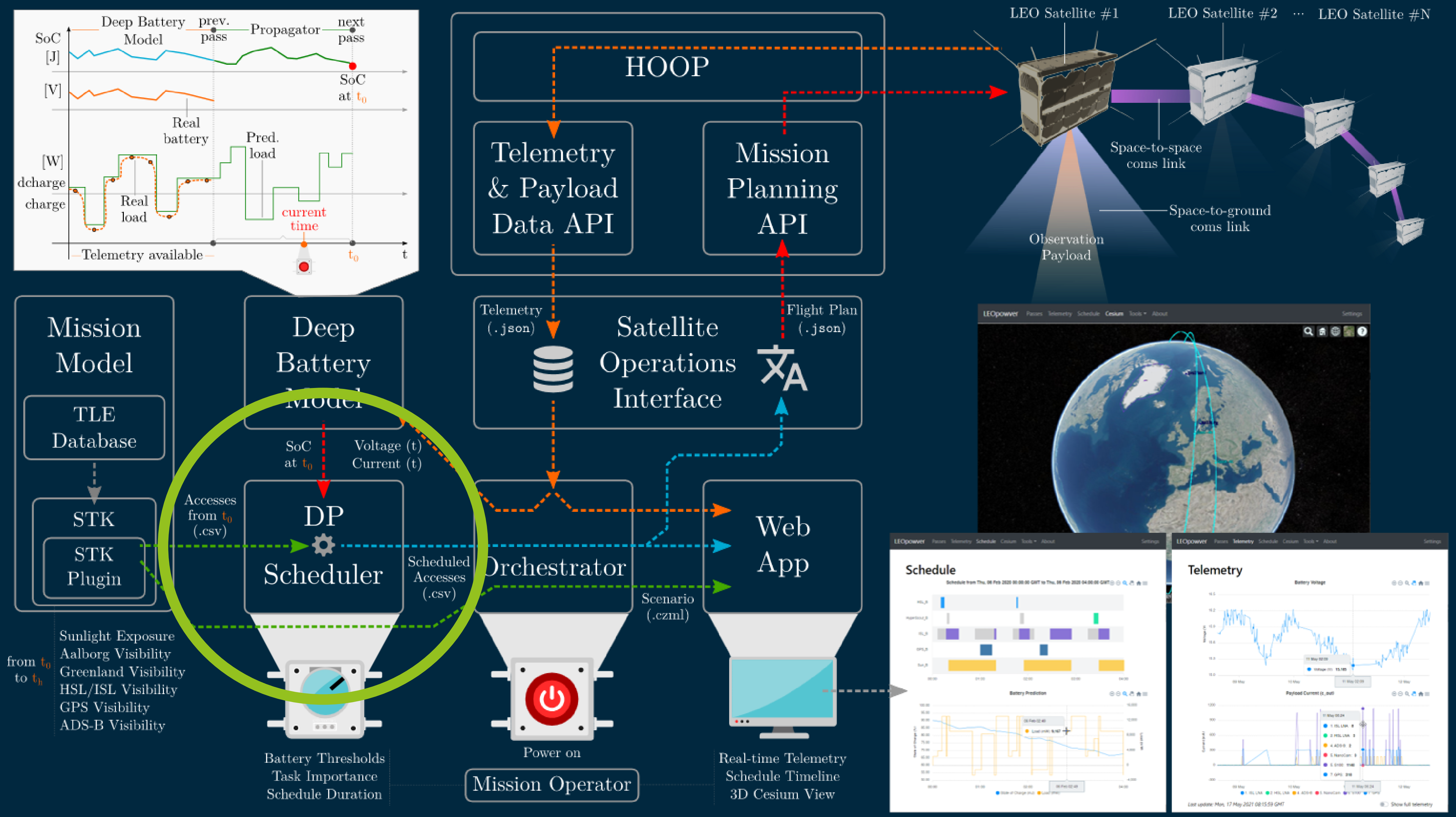
Strong support for battery-aware scheduling required!

LEOPOWVER Toolchain

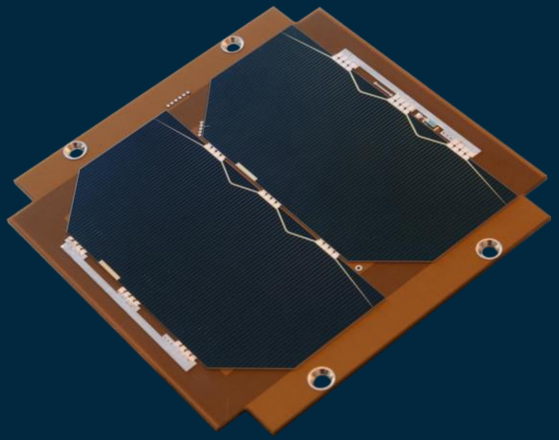


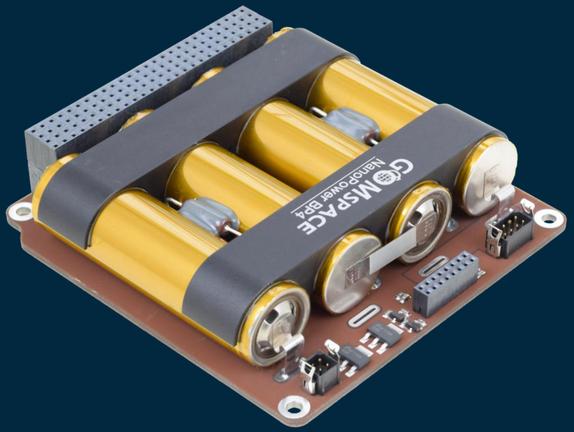

GomX-4A LLA Position
Time (UTCG): 11 May 2021 00:26:57.333
Lat (deg): 37.196
Lon (deg): 22.857
Alt (km): 481.544979
Lat Rate (deg/sec): 0.063103
Lon Rate (deg/sec): -0.017212
Alt Rate (km/sec): 0.012672
Svalbard
Greenland
Aalborg
GomX-4C
GomX-4A
Earth Inertial Axes
11 May 2021 00:26:57.333 Time Step: 1.00 sec
AGI

LEOPOWVER Toolchain

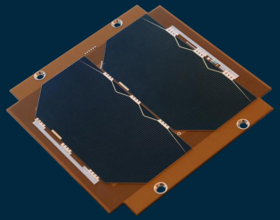


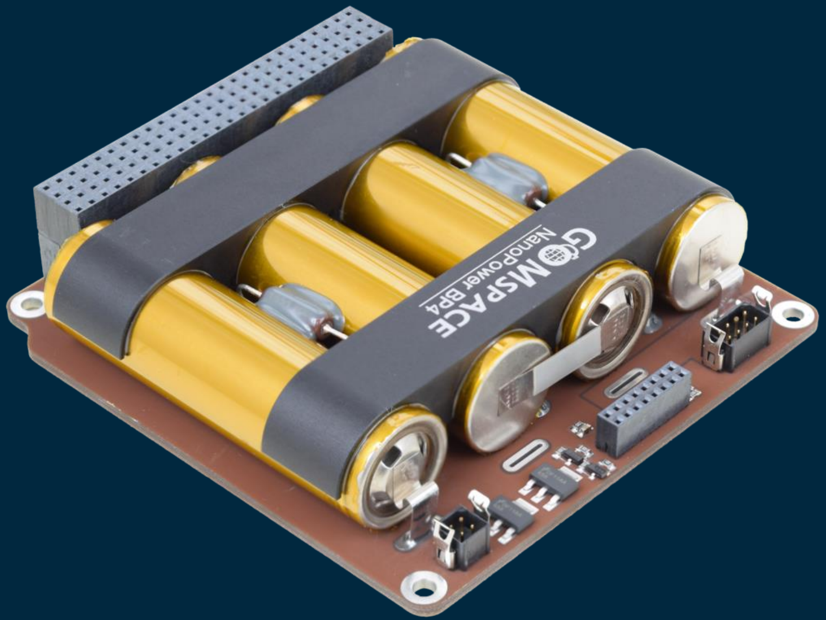
Batteries



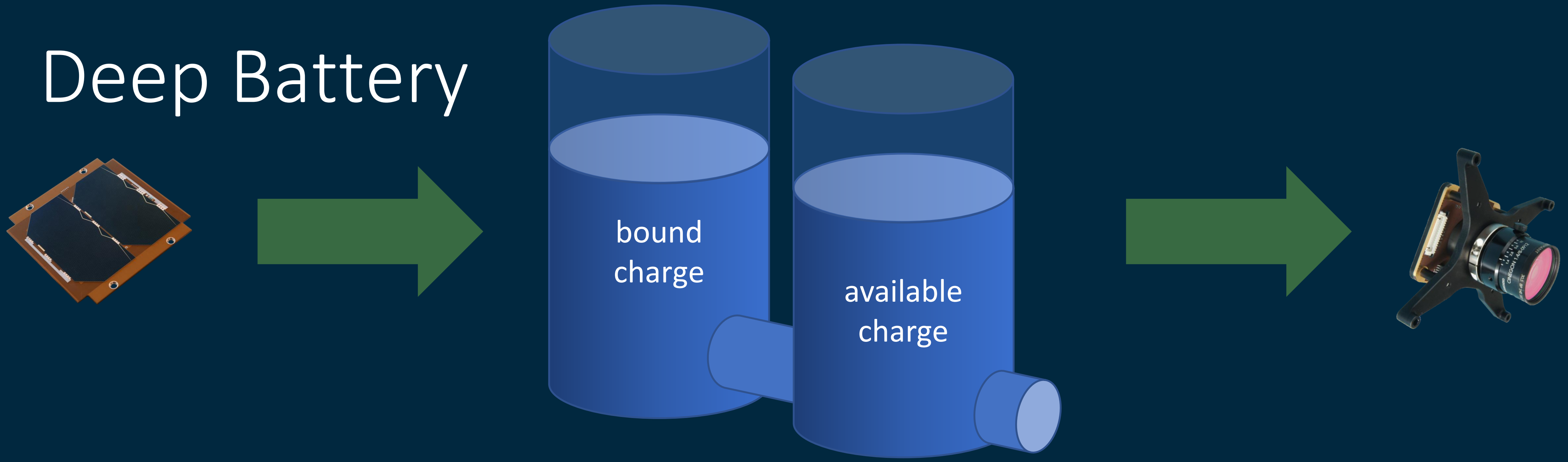


Batteries





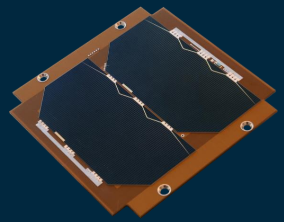
Deep Battery

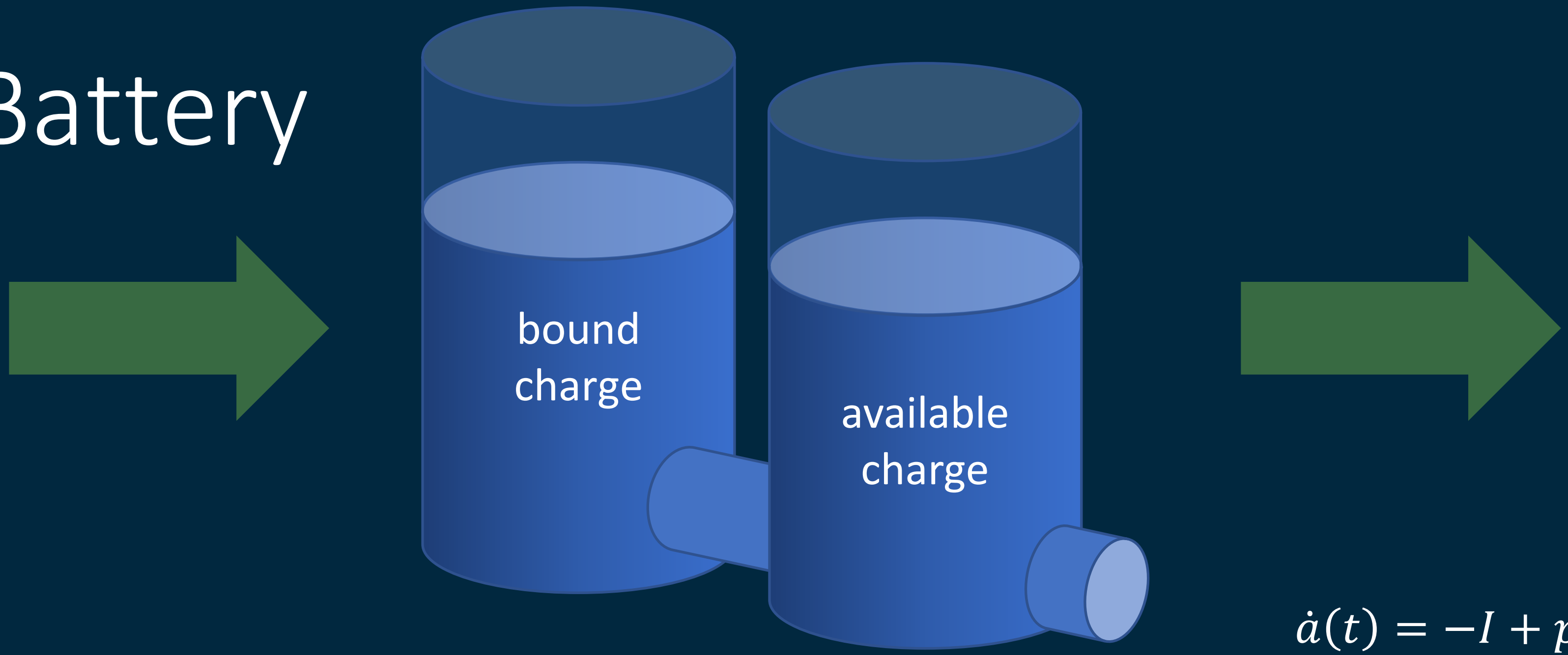


$$\dot{a}(t) = -I + p \cdot \left(\frac{b(t)}{1-c} - \frac{a(t)}{c} \right)$$

$$\dot{b}(t) = p \cdot \left(\frac{a(t)}{c} - \frac{b(t)}{1-c} \right)$$

Deep Battery



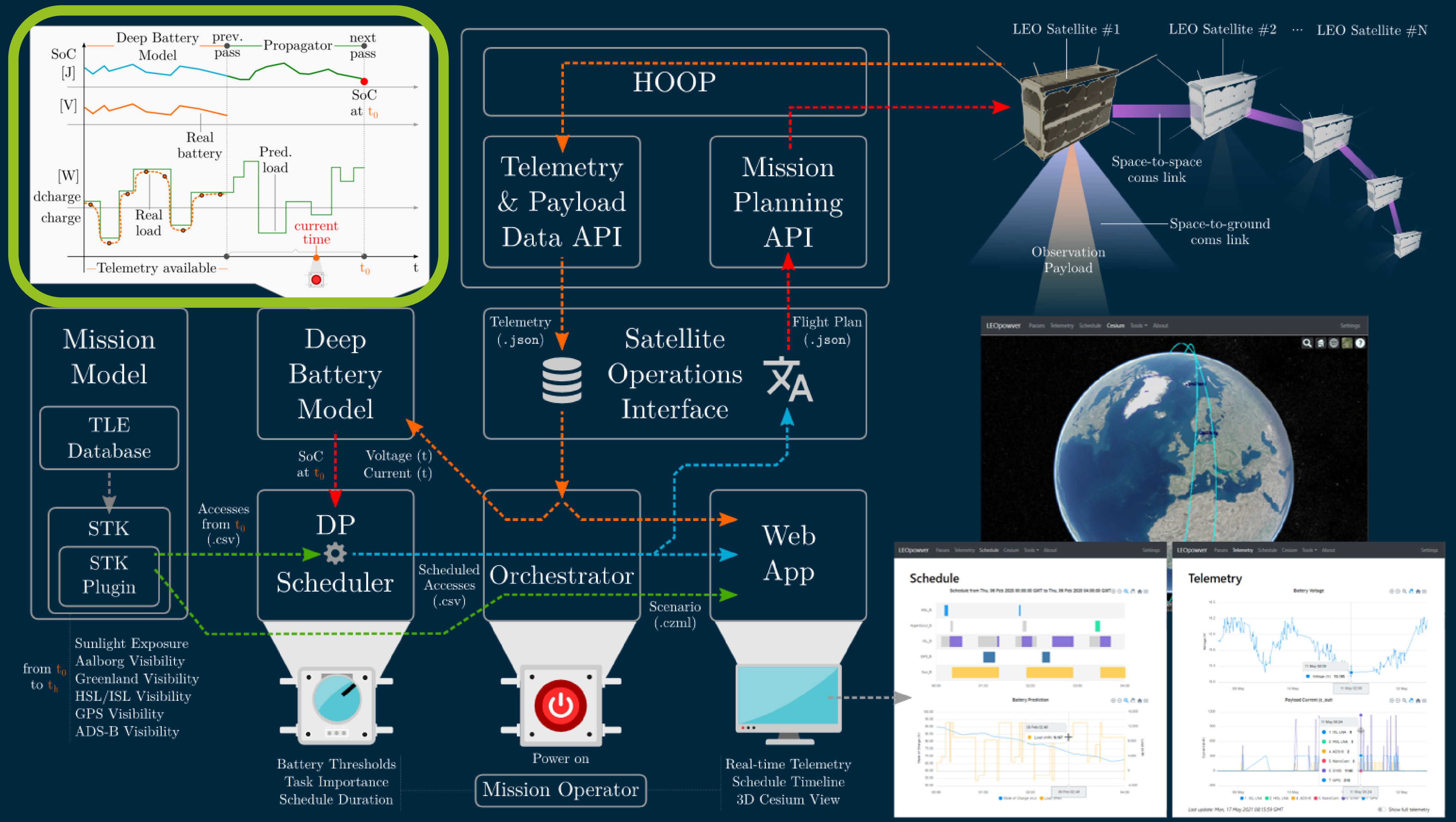


$$\dot{a}(t) = -I + p \cdot \left(\frac{b(t)}{1-c} - \frac{a(t)}{c} \right)$$

$$\dot{b}(t) = p \cdot \left(\frac{a(t)}{c} - \frac{b(t)}{1-c} \right)$$

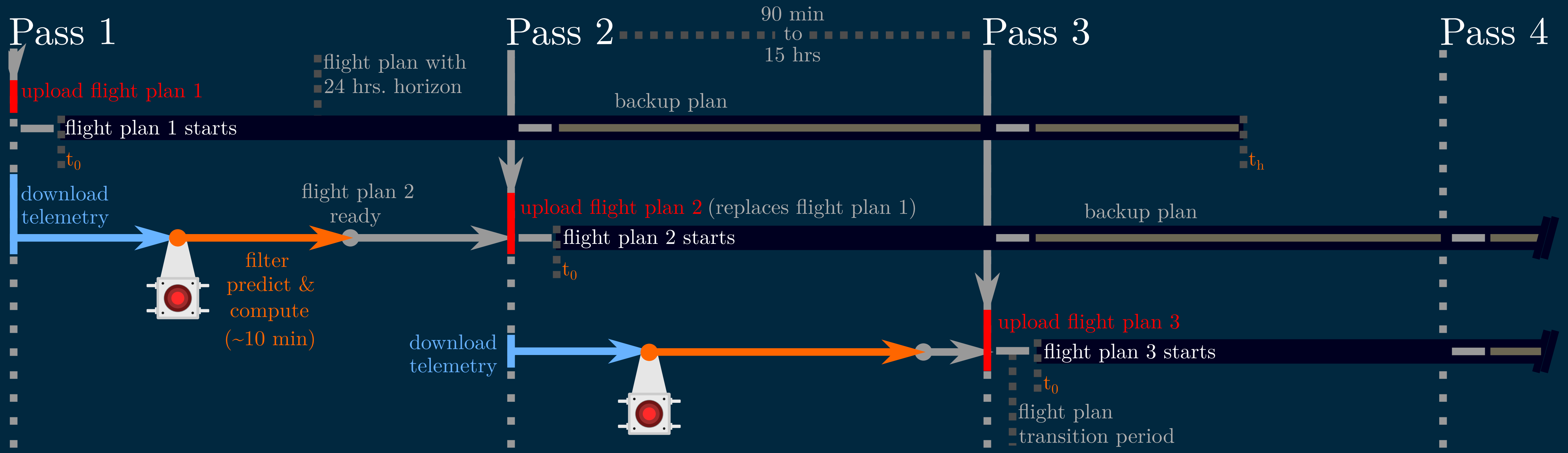
- **Rate-Capacity Effect:**
  quicker discharge reduces effective capacity
- **Recovery Effect:**
  charge is recovered during periods of no discharge

LEOPOWER Toolchain

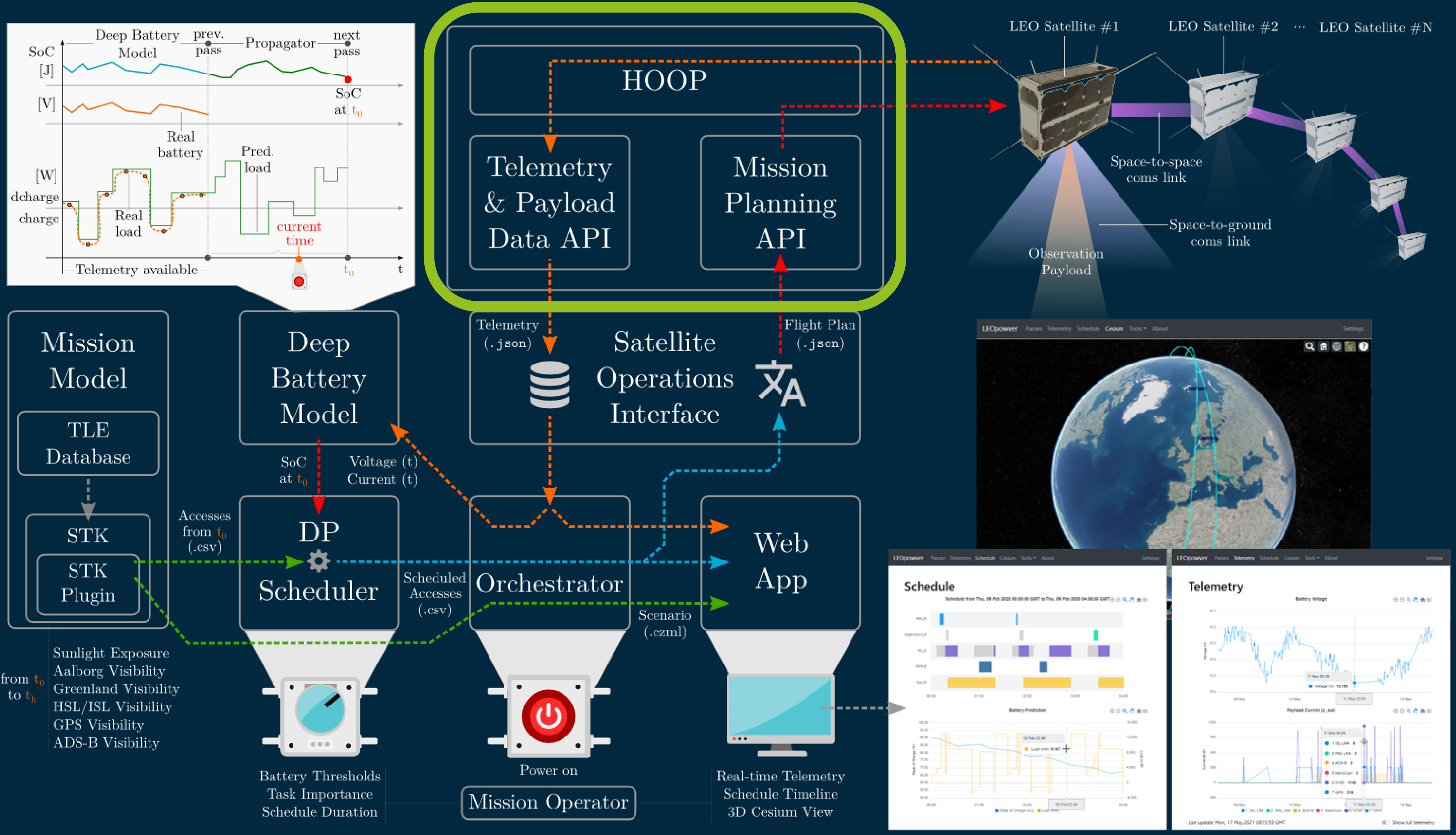


Receding-Horizon Scheduling

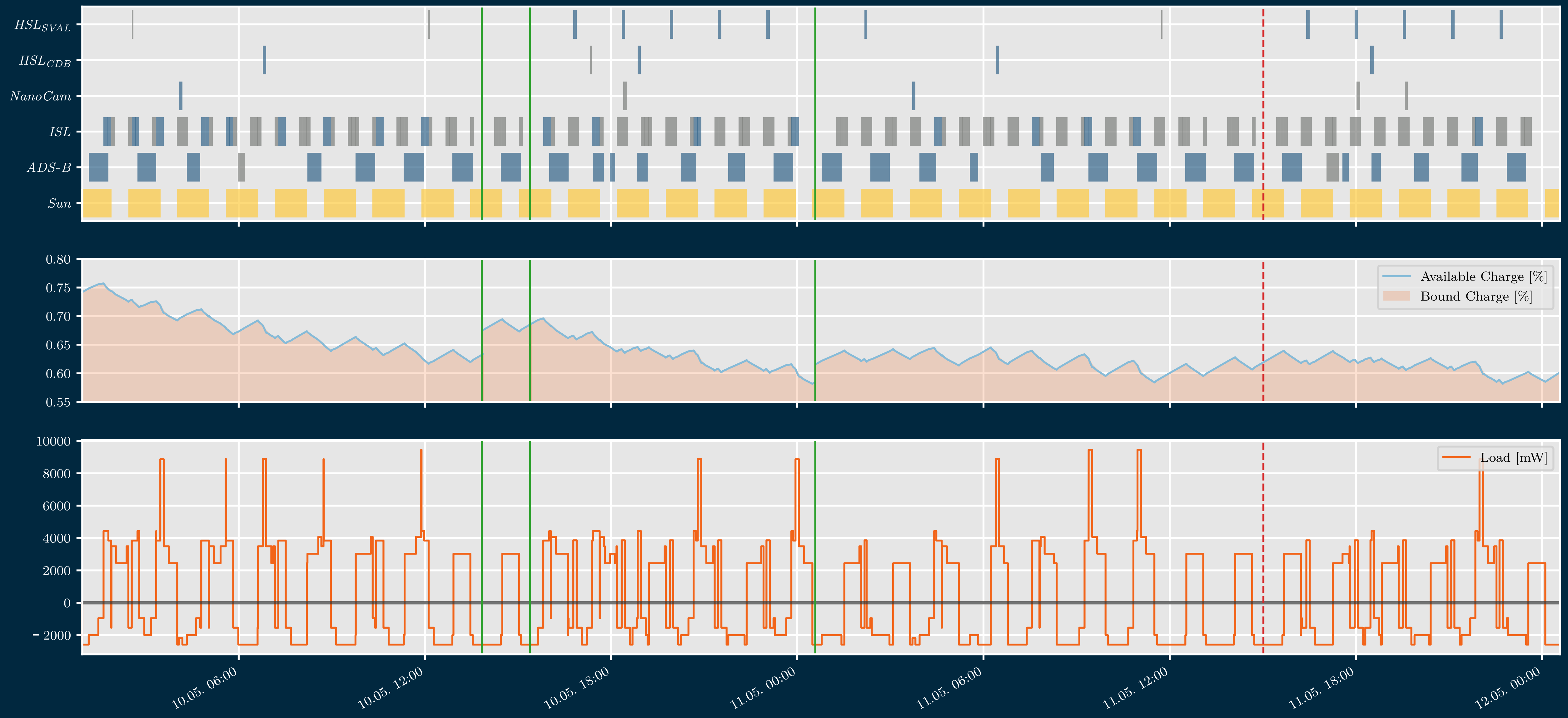
1. The scheduling horizon should not be a limit.
2. The battery model must not drift away from reality.



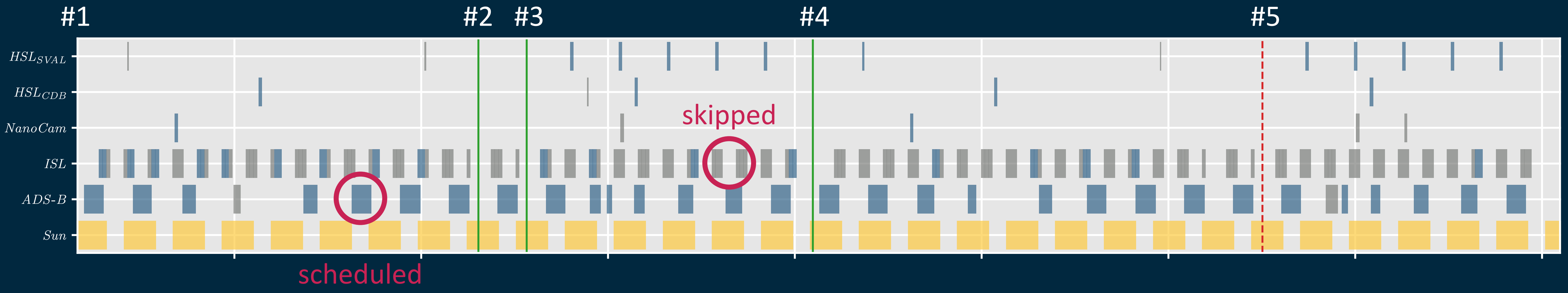
LEOPOWVER Toolchain



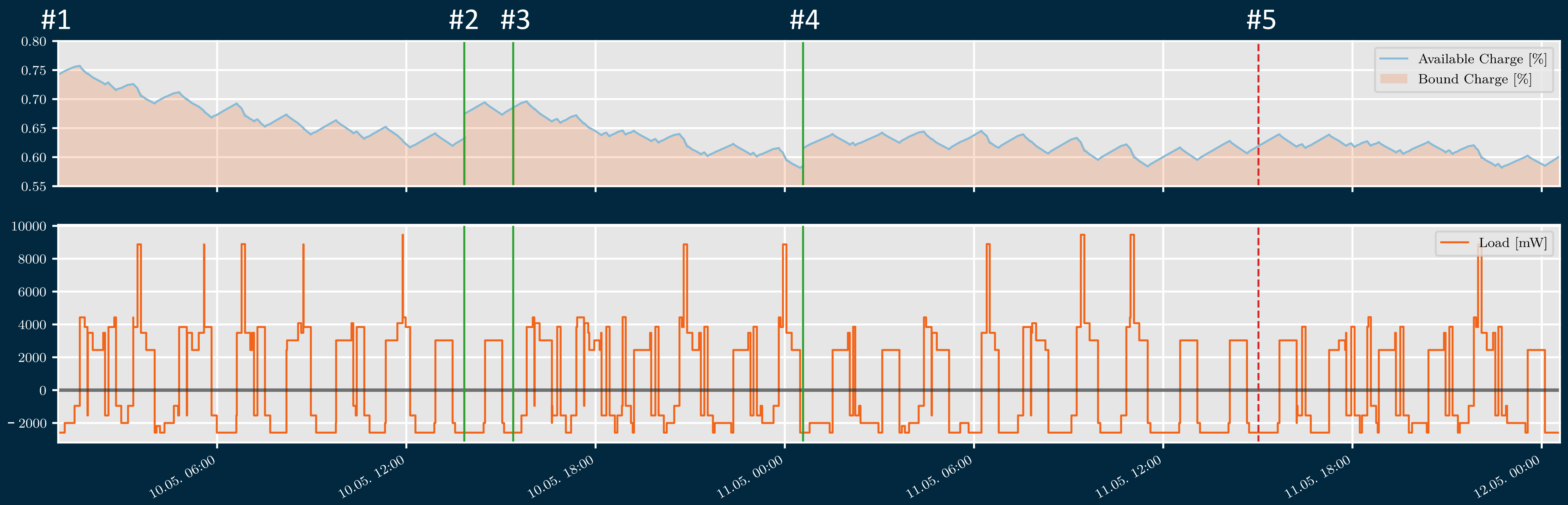
In-Orbit Experiments In May 2021



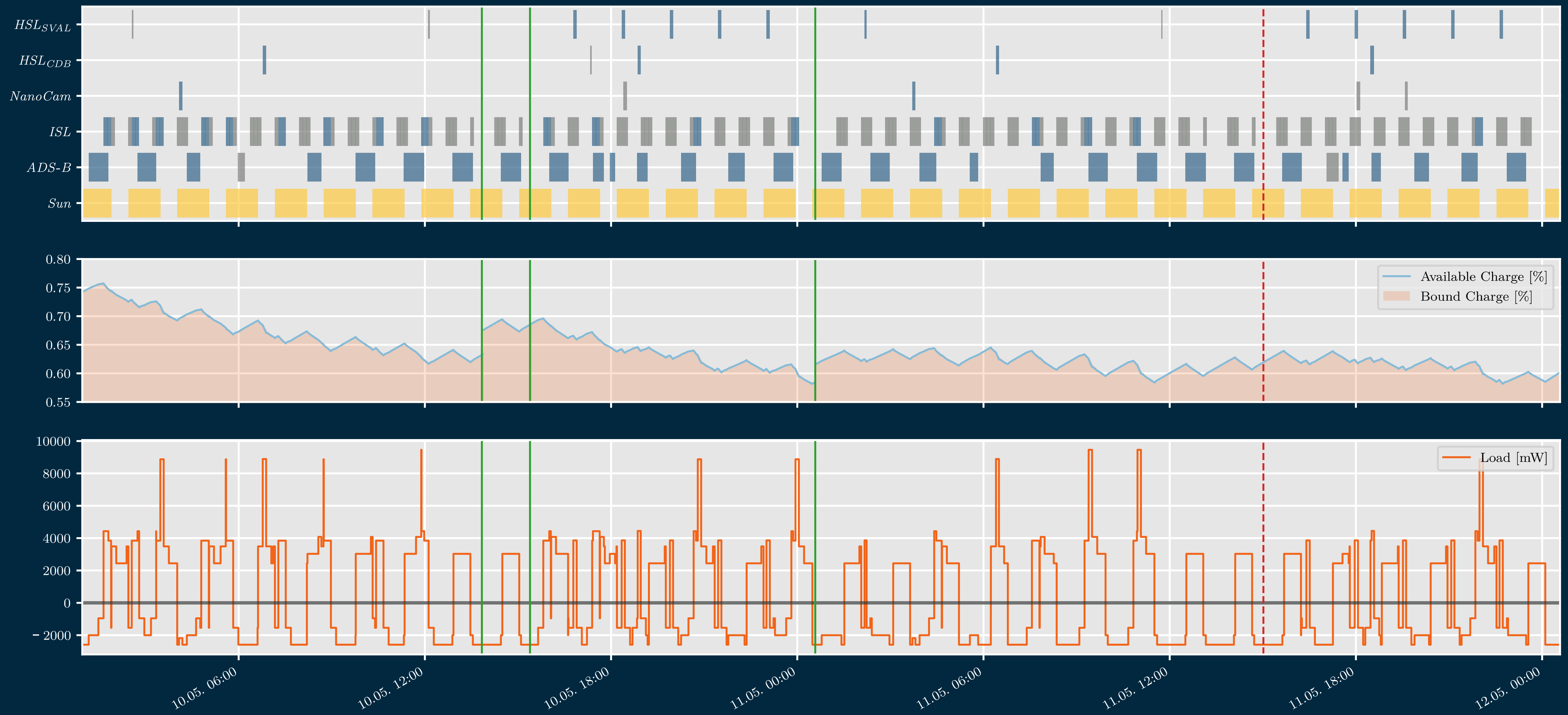
In-Orbit Experiments In May 2021



In-Orbit Experiments In May 2021



In-Orbit Experiments In May 2021




[SSC21-V-05]

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ABSTRACT

Recent breakthroughs in technology have led to a thriving "new space" culture in low-Earth orbit (LEO) in which performance and cost considerations dominate over resilience and reliability as mission goals. These advances create a manifold of opportunities for new research and business models but come with a number of striking new challenges. In particular, the size and weight limitations of low-Earth orbit small satellites make their successful operation rest on a fine balance between solar power infeed and the power demands of the mission payload and supporting platform technologies, buffered by on-board battery storage. At the same time, these satellites are being rolled out as part of ever-larger constellations and mega-constellations. Altogether, this induces a number of challenging computational problems related to the recurring need to make decisions about which task each satellite is to effectuate next. Against this background, GOMSPACE and Saarland University have joined forces to develop highly sophisticated software-based *automated* solutions rooted in *optimal algorithmic* and *self-improving learning techniques*, all this *validated* in modern nanosatellite networked missions operating in orbit.

The paper introduces the GOMSPACE Hands-Off Operations Platform (HOOP), an automated, flexible, and scalable end-to-end satellite operation framework for commanding and monitoring subsystems, single-satellites, or constellation-class missions. To this, the POWVER initiative at Saarland University has contributed state-of-the-art dynamic programming and learning techniques based on profound battery and electric power budget models. These models are continually kept accurate by extrapolating data from telemetry received from satellites. The resulting machine learning approach delivers optimal, efficient, scalable, usable, and robust flight plans, which are provisioned to the satellites with zero need for human intervention—but which are still under the full control of the mission operator. We report on insights gained while validating the integrated POWVER-HOOP approach in orbit on the dual-satellite mission GOMX–4 by GOMSPACE that is currently in orbit.

Stock 1 35^{th} Annual Small Satellite Conference

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- unique approach for **fully automated** satellite constellation operations
  - using optimal algorithms
  - based on accurate self-learning battery models
- integration with HOOP proves **flexibility** and **usability** by space engineers
- **in-orbit experiments** with GOMX-4 validate accuracy, efficiency, scalability, and robustness of the approach

GOMSPACE
UNIVERSITÄT DES SAARLANDES