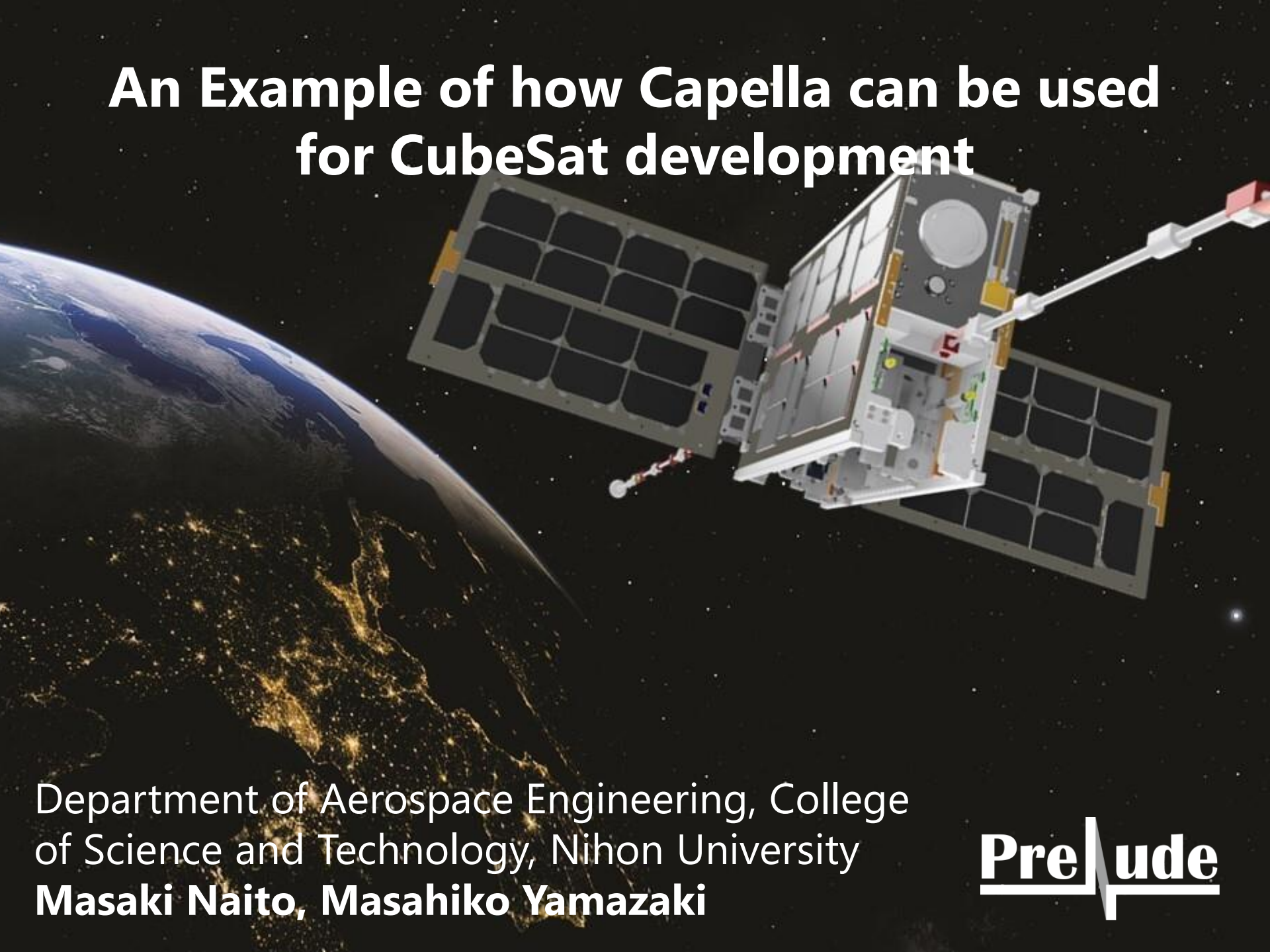
An Example of how Capella can be used for CubeSat development



Department of Aerospace Engineering, College of Science and Technology, Nihon University
Masaki Naito, Masahiko Yamazaki

Prelude

Today’s contents

CapellaDays ONLINE 2024

- Introduction of Speakers
- Why we adapted Capella?
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  - Future plans

Introduction of Speakers

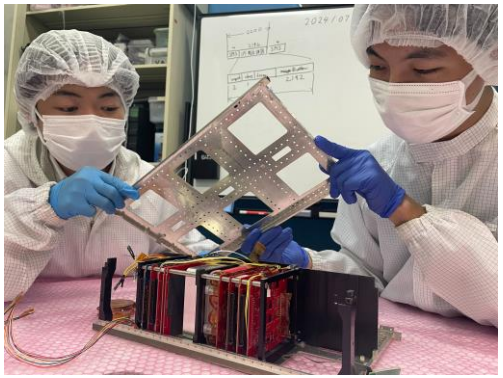
Masaki Naito

4th year in Nihon University
(Undergraduate)

- **6U-sized Satellite PRELUDE Project**
  - Sub Project Manager
  - System Integrator
  - On-board software developer
- HEPTA-Sat Training TA

Research Topic

CubeSat software modeling and optimization
by using MBSE including Capella



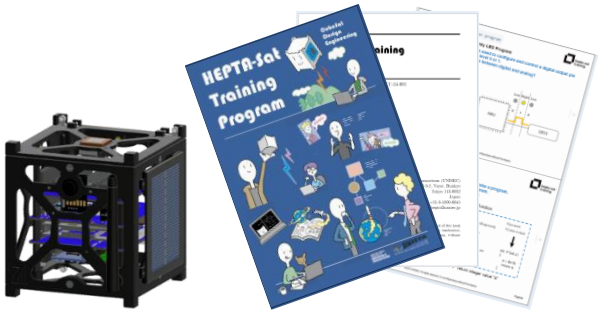
Satellite Assembly

Laboratory Members

Introduction of Speakers

- Associate Professor in the Department of Aerospace Engineering, Nihon University

- Vice chairman of UNISEC (University Space Engineering Consortium)

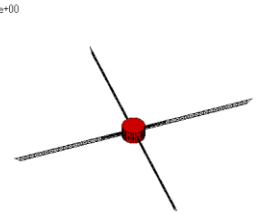


Capacity Building Program through CubeSat Hands-on

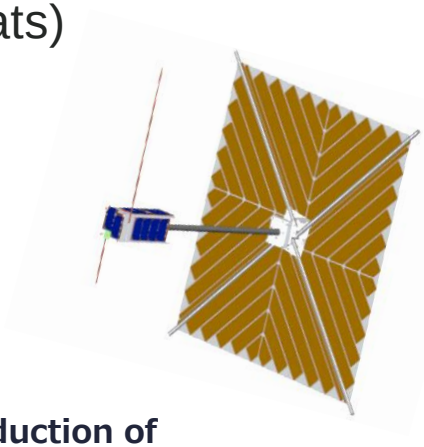
Research Topics

- Large Space Structures (Gossamer Structures)
- Nanosatellite Systems (CubeSats)

Educational CubeSat



Model Order Reduction of Flexible Space Structure

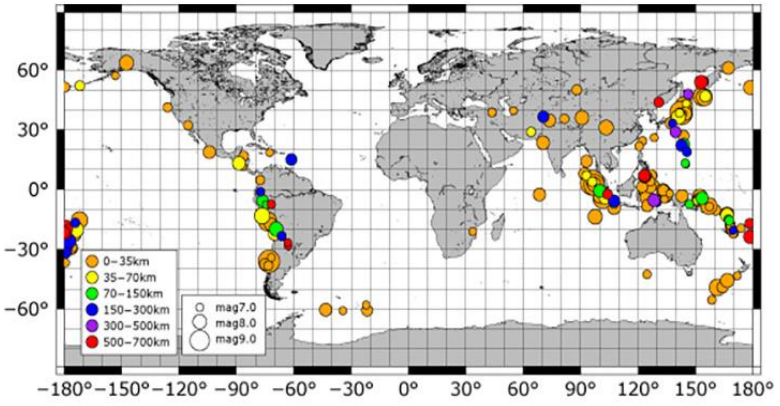


Precursory Electric Field Observation CubeSat

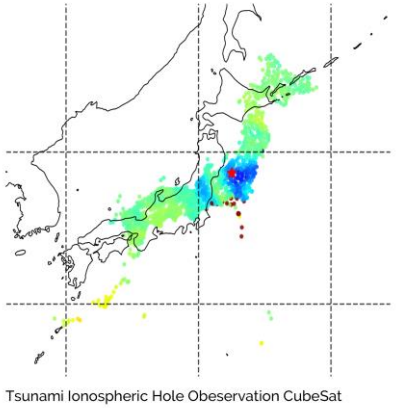
Research and Project

- **PRELUDE Satellite Project (will launch FY2025)**
  - Nanosatellite for observation of earthquake precursor
  - Projects that integrate science and engineering through industry-academia-government collaboration
- **Neptune Satellite Project**
  - Nanosatellite for early tsunami prediction
- **HEPTA-Sat Training**
  - Capacity building program through CubeSat hands-on practice

Modeling of satellite systems and satellite observation data and solving social problems



Precursory Electric Field Observation



Early Tsunami Prediction

Capacity Building for Space Research

Today’s contents

- Introduction of Speakers
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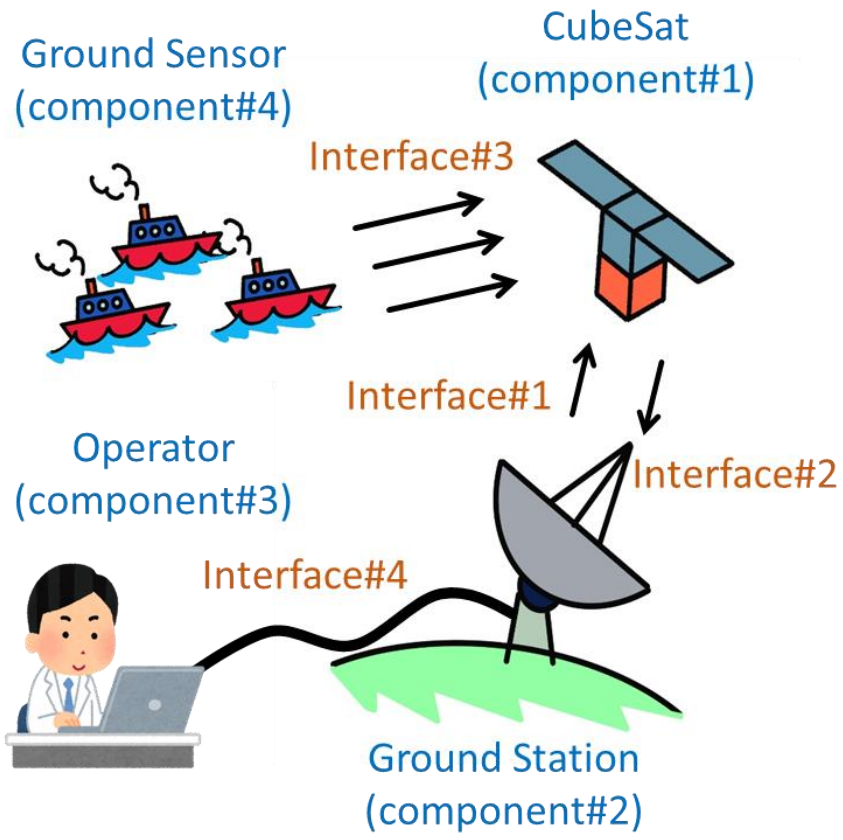
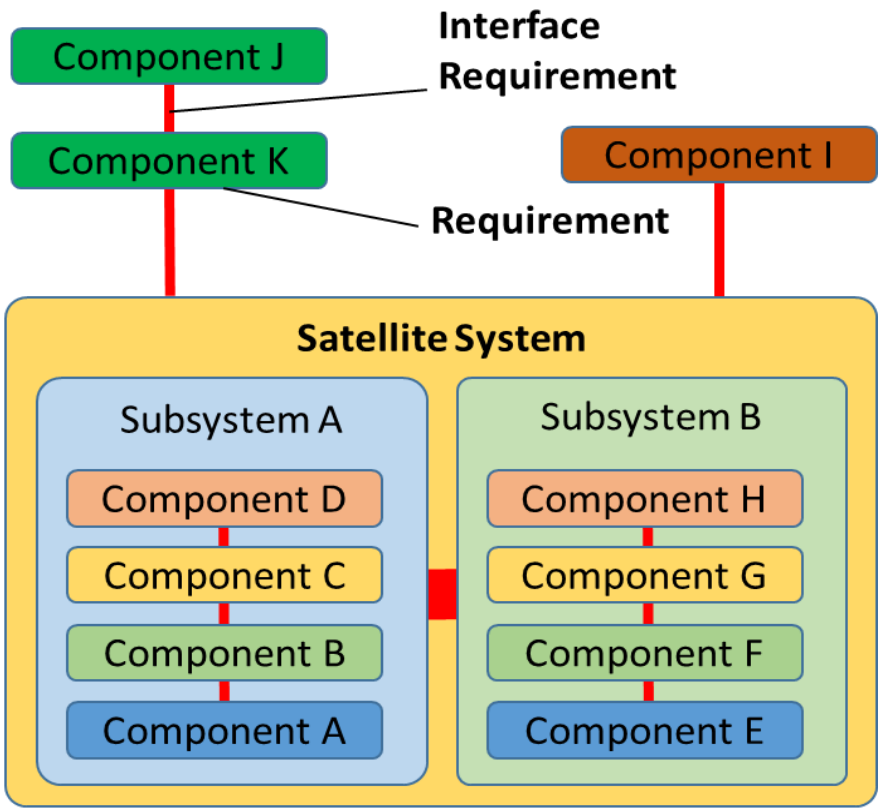
What are space systems?

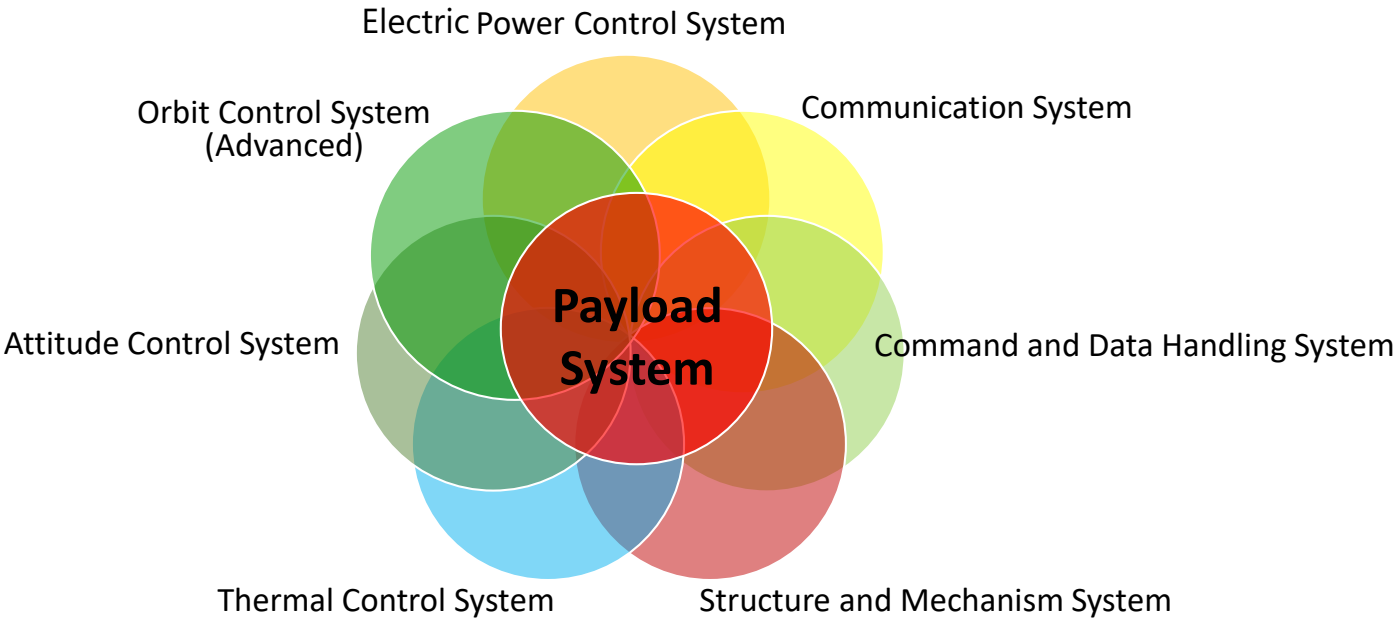
- A system consists of various elements such as hardware, software, people, data, and services, which work together appropriately to achieve a goal.





What are space systems?

- Developing a system means clarifying the boundaries of the system and designing an operational, functional, and physical design that is consistent with the requirements and constraints of the entire life cycle.
- Evaluated from a variety of perspectives, both numerically and experimentally.



Payloads do not operate by themselves but rather execute their roles in <u>combination with other on-board hardware, software, and interfaces</u>.

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CapellaDays ONLINE 2024

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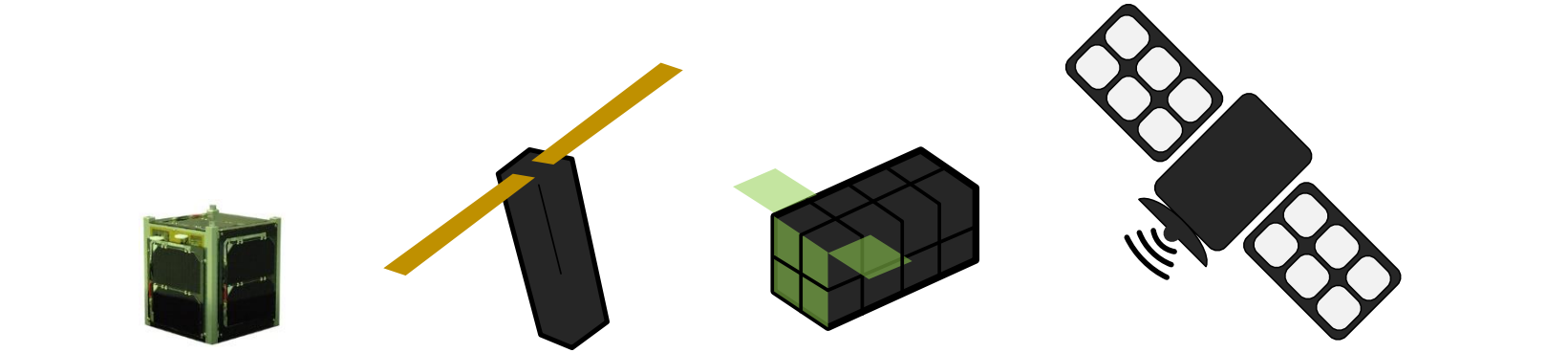
What are CubeSats?

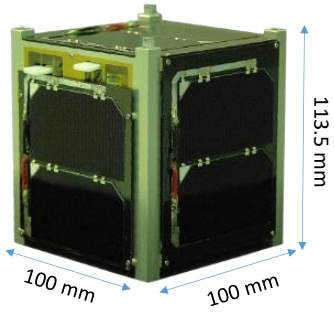
Sizes of Satellites: The definitions of satellite classes are slightly different from country to country. Generally, large satellites are multi-purpose and use on high accuracy missions. Pico/Nano/Micro satellites may perform similar missions as the large satellites by forming a constellation.



Picosatellites (0.1-0.99 kg)	Nanosatellites (1-10 kg)	Microsatellites (10-100 kg)	Small/Medium satellites (100-1000 kg)
Mainly technology demonstration and education. **Best first challenge for students.**	Simple missions, not so high performance but **cost-effective**	A few special missions	Earth observation, scientific missions, technology verification, monitoring, etc.

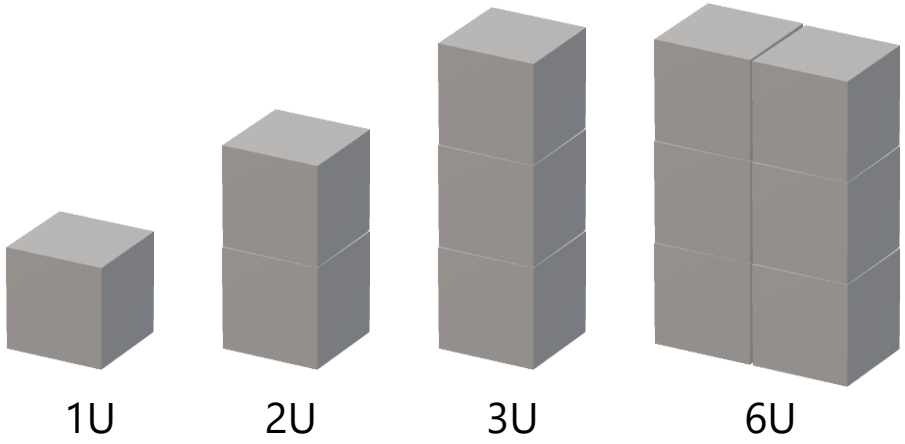
What are CubeSats?

- The specific standards for CubeSats help reduce costs.
- A 1U CubeSat is a ***10 cm cube*** with a mass of approximately ***1 to 1.33 kg***.
- CubeSats come in several sizes, which are based on the ***standard CubeSat unit (called 1U)***.



1U CubeSat SEEDS-II
© Nihon University

W6U CubeSat PRELUDE
© Nihon University



Standard sizes of CubeSat

What are CubeSats?

- Nano-satellites that can be developed at **low cost** and in a **short period** of time.
- They are being used such as being utilized in **education**, **business**, and **science**.
- Not only replacing conventional technologies, but also complementary to them.

Examples of UNISEC Japan Satellites from 2003 to 2019 (R&D, Commercial)

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CapellaDays ONLINE 2024

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What we hope to achieve with Capella

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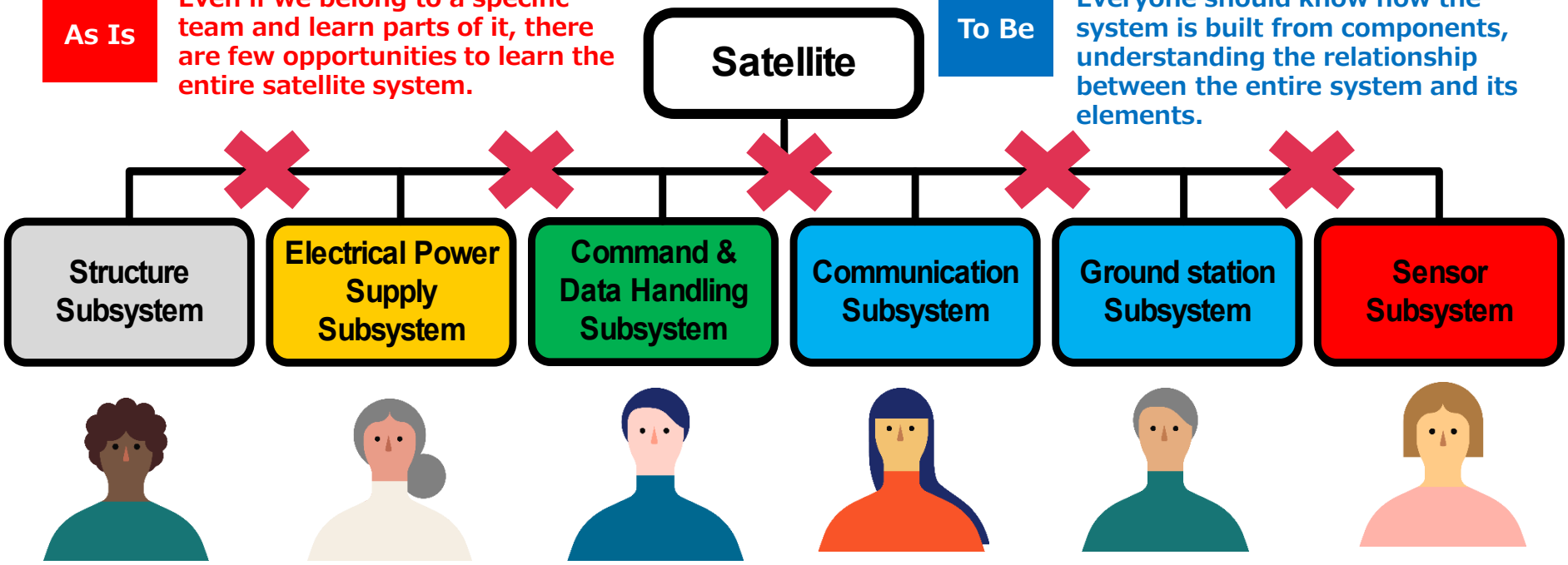
- In the real space project, it is sometimes hard to gain knowledge or experience of the whole development process because the roles are divided among team members.

As Is Even if we belong to a specific team and learn parts of it, there are few opportunities to learn the entire satellite system.

To Be Everyone should know how the system is built from components, understanding the relationship between the entire system and its elements.



➡ **MBSE provides a visual understanding of other subsystems and the overall satellite system, leading to a design that optimizes the entire satellite.**

What we hope to achieve with Capella

- Not necessarily created by professionals, so design and verification omissions are likely to occur.
  - Many university students are not familiar with satellite design.
  - Verification omissions can lead to the loss of the satellite.

➡ **Drawing and visualizing the model diagram makes it easier to notice omissions.**

- In a university institution, knowledge and technology losses occur due to member turnover.
  - High turnover rate (1/3 members graduate every year)

➡ **By leaving information on the model diagram, it is easier for new members to understand the system.**

- It is necessary to develop the system under severe constraints of time, budget, and human resources.

➡ **We want to optimize satellite system design and development to accomplish our mission with limited resources.**

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CapellaDays ONLINE 2024

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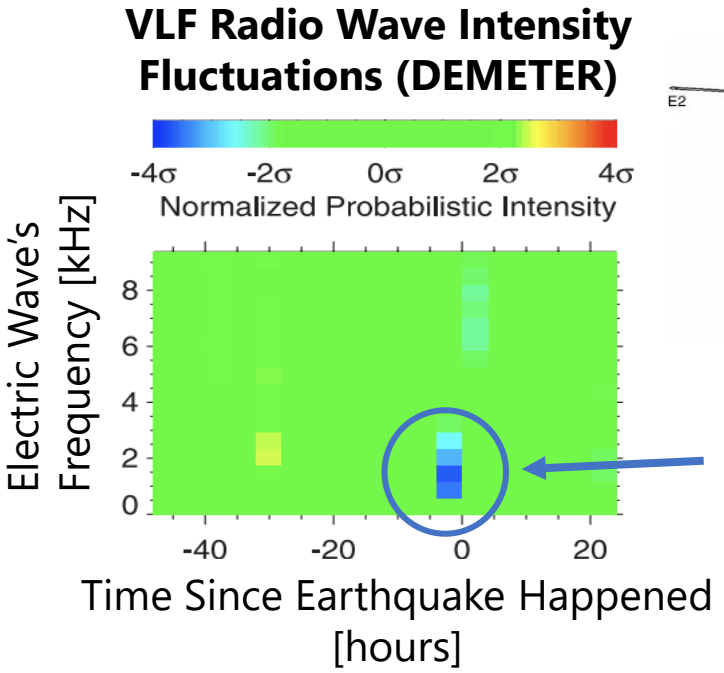
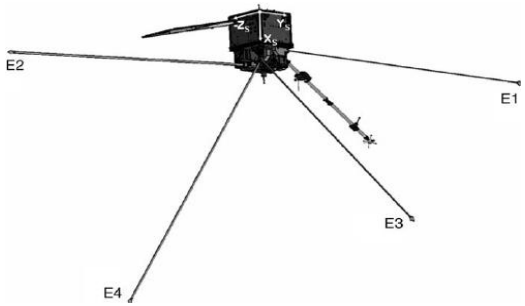
Pre-Earthquake Ionospheric Perturbation

- The small satellite DEMETER was developed by CNES (France) to investigate earthquake precursor in the ionosphere in 2004.





DEMETER Sat:
- About 130kg
- Altitude 700km
- Sun Synchronous Orbit

About a 1.7kHz electric wave intensity decrease about 4hours before earthquakes (statistically significant)

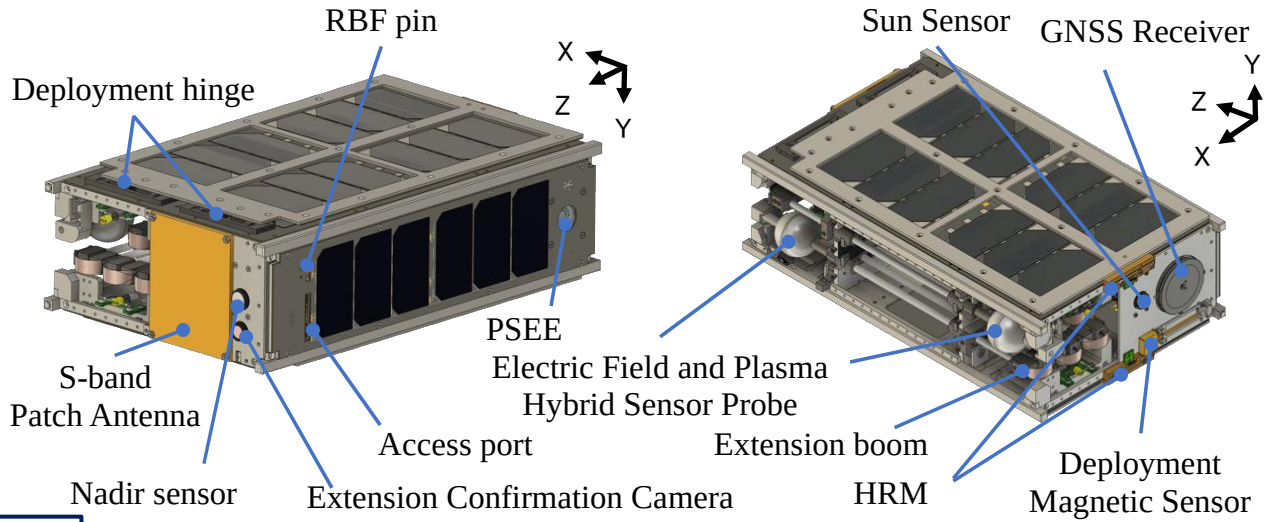
Namec et al., GRL, 2008, Nemec et al., JGR, 2009, Pisa et al,,JGR, 2013

- The mechanism behind these fluctuations remains unknown.
- Multi-aspect statistical evaluations are needed to identify any link with earthquakes.
- There is a shortage of major earthquake cases with high-quality data.

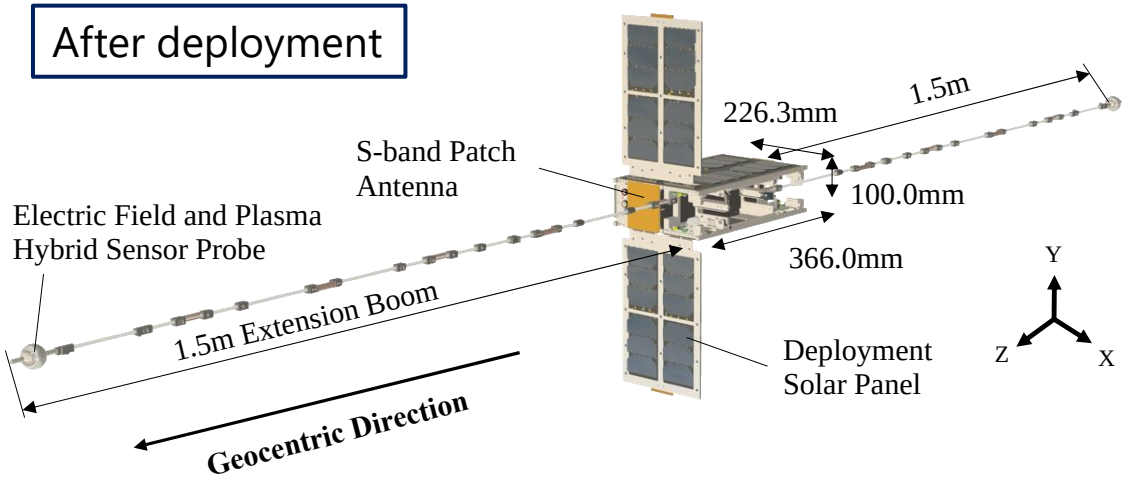
W6U CubeSat PRELUDE

To increase the number of ionospheric observation data and clarify the mechanism of the phenomena, we are developing the PRELUDE satellite.

Launch state



After deployment

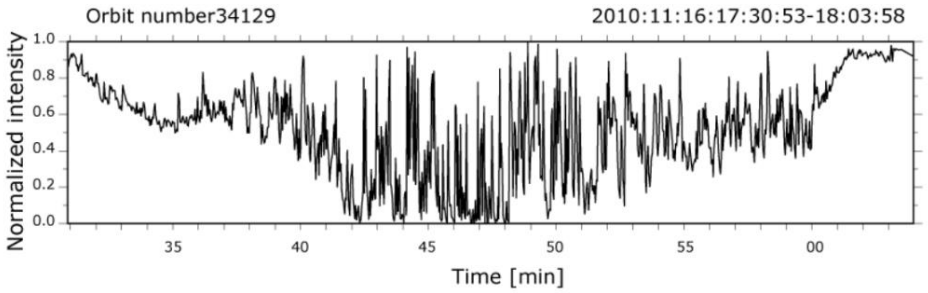


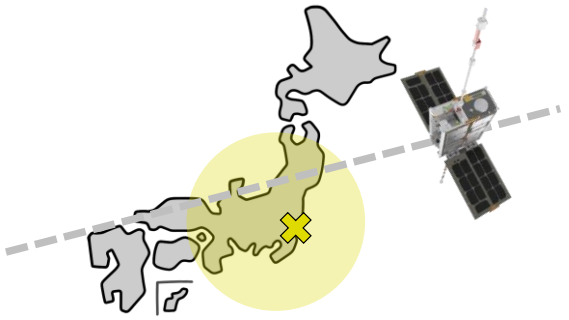
Mass: 8kg
Launch Vehicle:
JAXA Epsilon S Rocket
Initial Altitude: 540km
Orbit: Sun Synchronous Orbit

Three Main Missions of PRELUDE

1. Detection and statistical evaluation of earthquake precursor

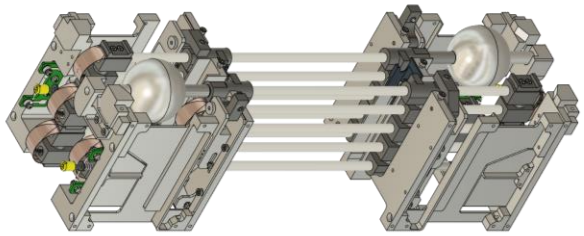
- ✓ Observing the ionosphere





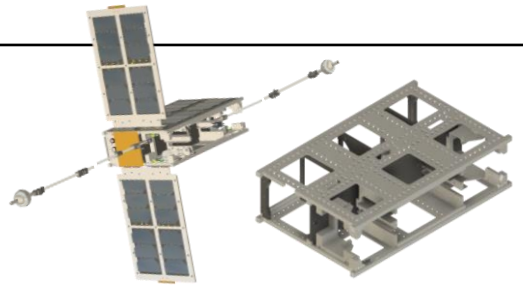
2. Development of 3U size payload for electric field and plasma hybrid observation

- ✓ Only 3U size
- ✓ Simple interface
- ✓ It can also be equipped on other satellites



3. Development of CubeSat platform for electromagnetic observation

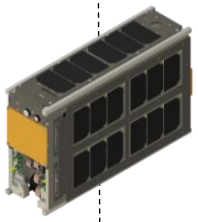
- ✓ Reducing electromagnetic noise
- ✓ Constellation through international collaboration



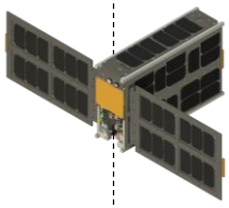
Mission Sequence and Overview

Time[month]

0



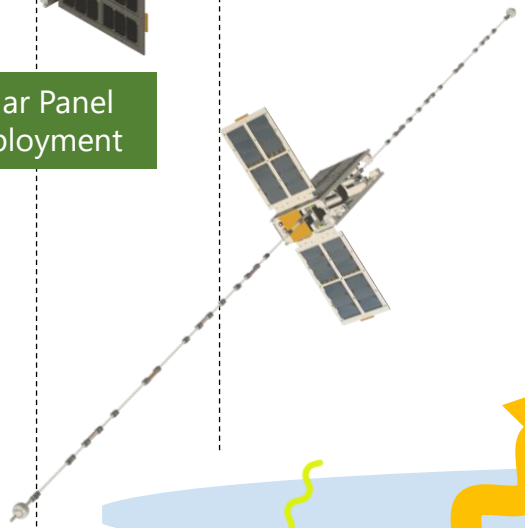
Released



Solar Panel Deployment

3 – 27

Electric Field and Plasma Probe Deployment



Ionospheric Observation

By observing lightning and artificial VLF waves, when the satellite passes over the epicenter, ionospheric change preceding earthquakes can be detected.

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Arcadia method layers

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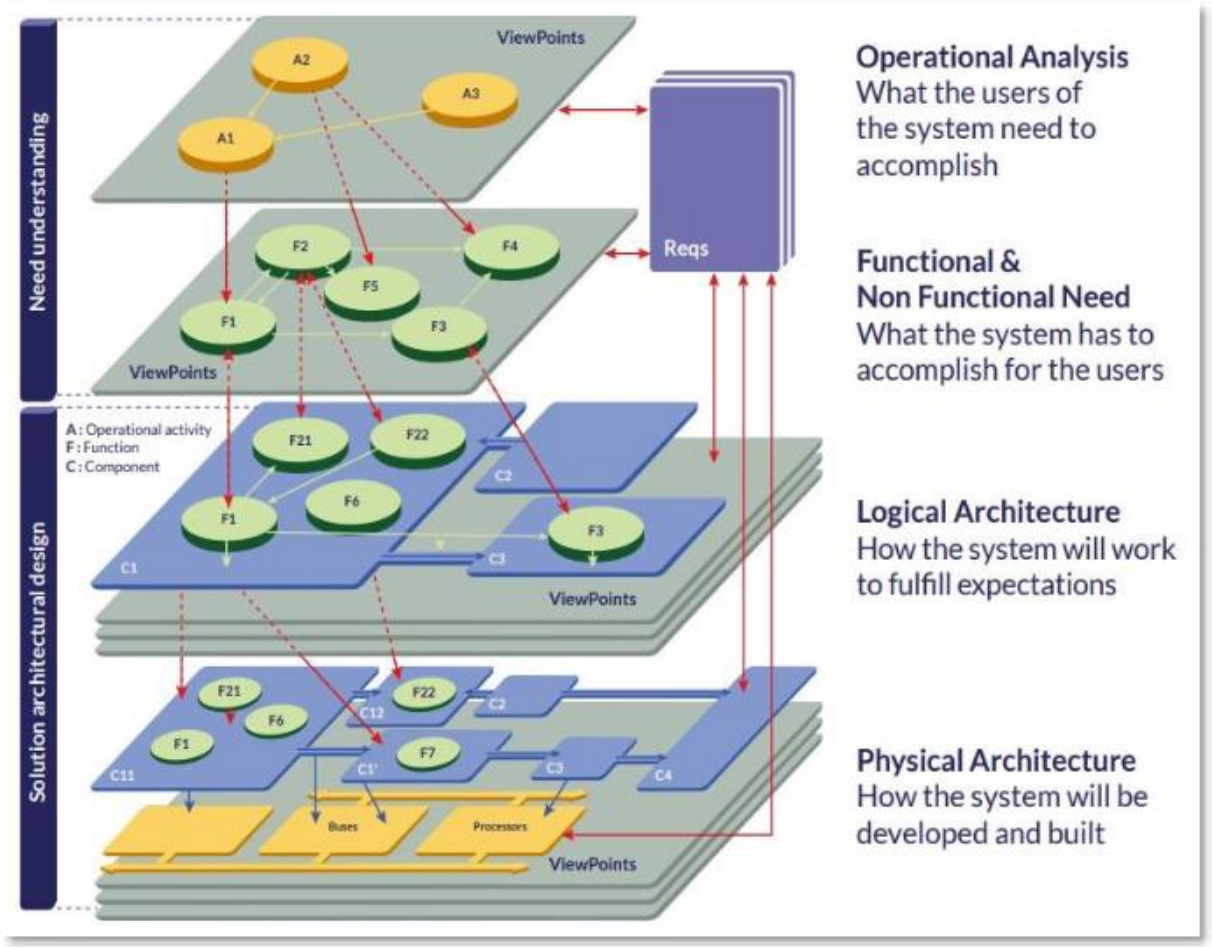
Analysis is available at different levels of abstraction.



Arcadia Method Layers Overview[1)]

1) Hélder Castro: MBSE with Arcadia method step-by-step, https://www.slideshare.net/slideshow/mbse-with-arcadia-methodpdf-256664096/256664096, accessed November 7, 2024

Our Capella models: Overview

- Main developer of PRELUDE is Nihon University.
  - We are responsible for all system design, development, and operation, from overall satellite design to operation.

- We used Capella as shown in the table below.
- In our case, the satellite system was already designed before we started using Capella.
  - We used the logical layer and physical layer for verification of the satellite system design and optimization of the software.
  - We are still making models in physical layer.

Layer	Objective
Operational Layer	Identifying stakeholders Clarifying the boundaries of the system
System Layer	Expression of functions required for the entire satellite depending on the mission
Logical Layer	Expression of functions required for subsystems
Physical Layer	Expression of functions required for components

Our Capella models: Operational Layer

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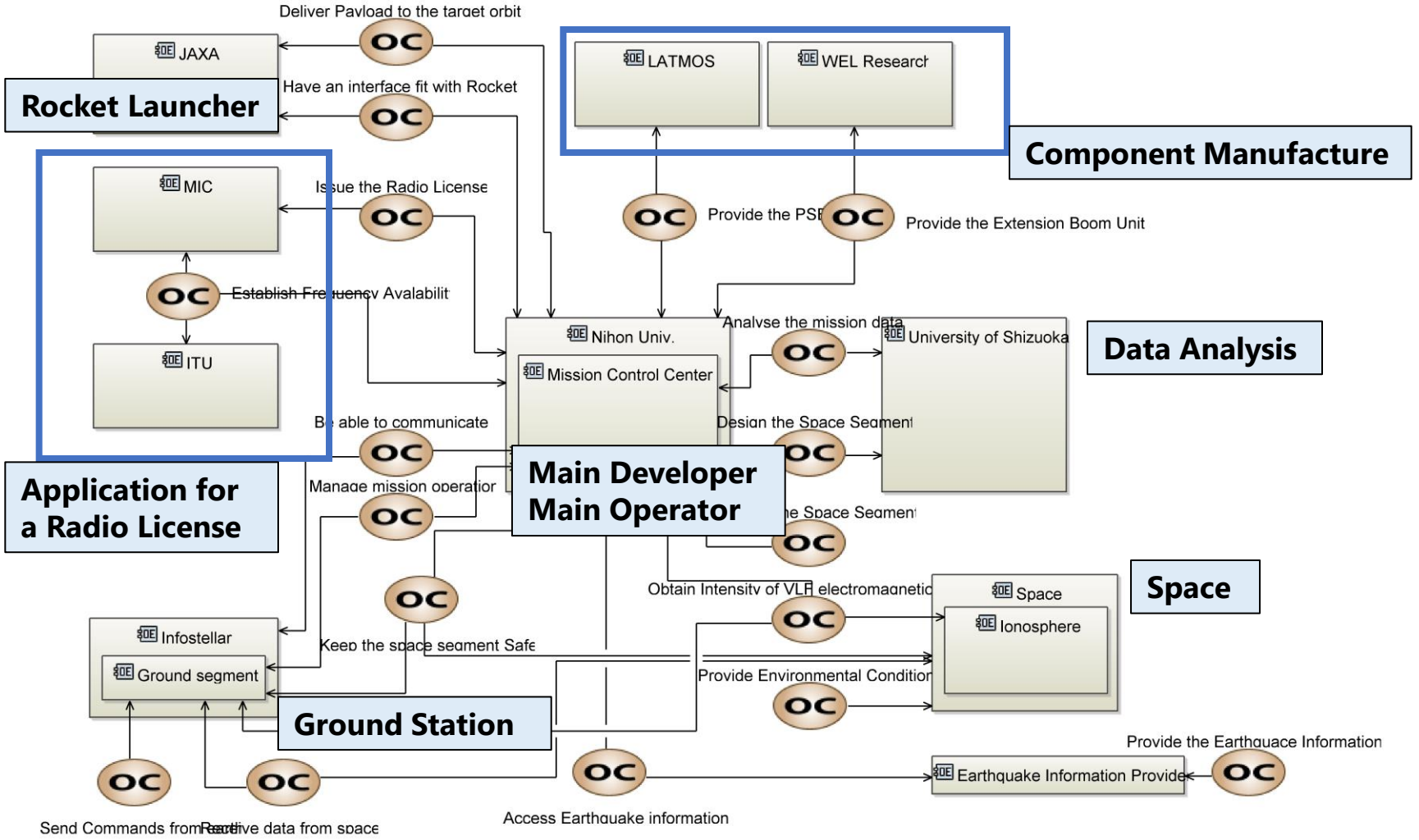
- Identifying stakeholders
- Clarifying the boundaries of the system

[OCB] Operational Capabilities



Our Capella models: Operational Layer

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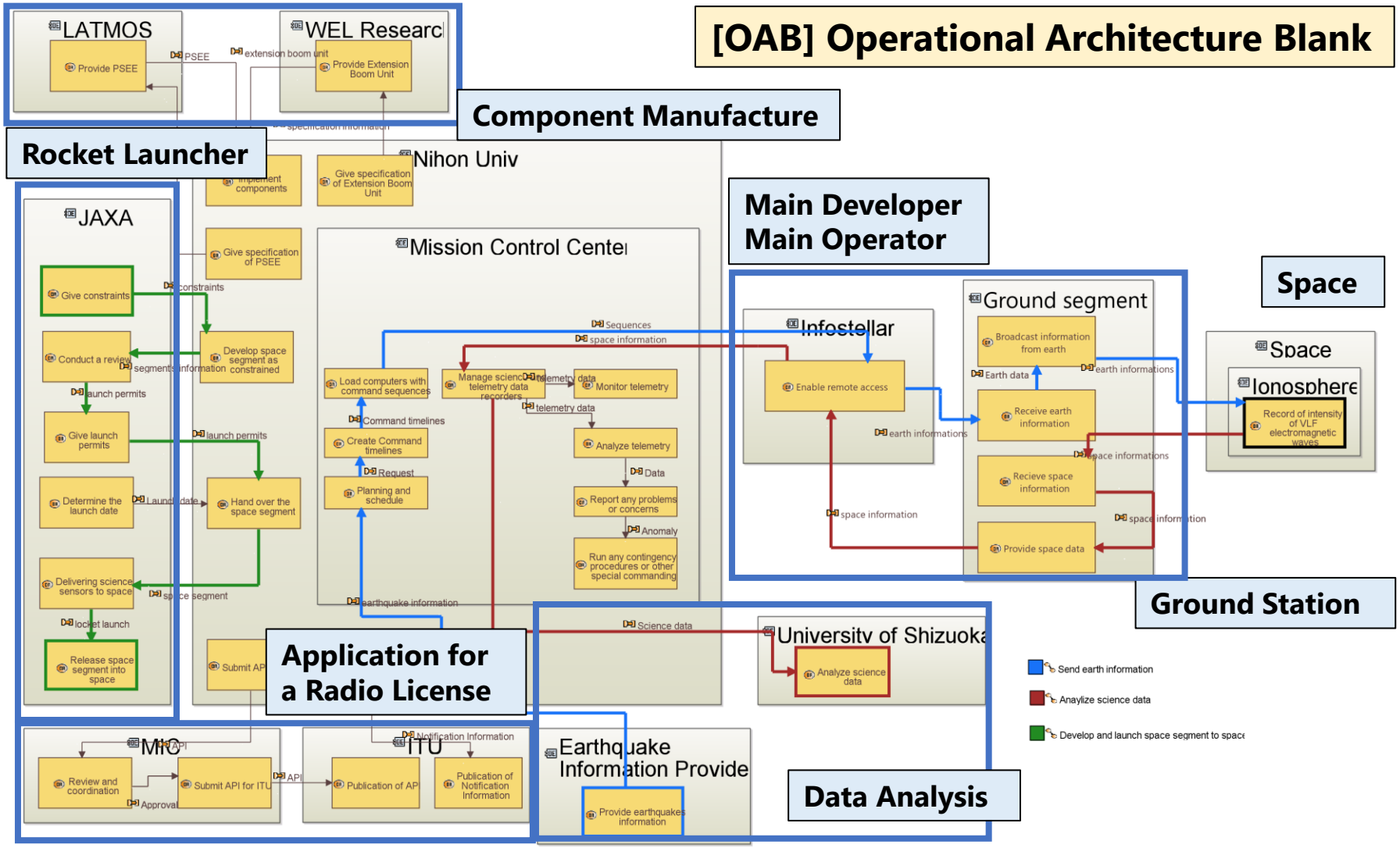
- It gives an overall picture of the operation.
- Clarify the “objective” when operating the system.



Our Capella models: Operational Layer

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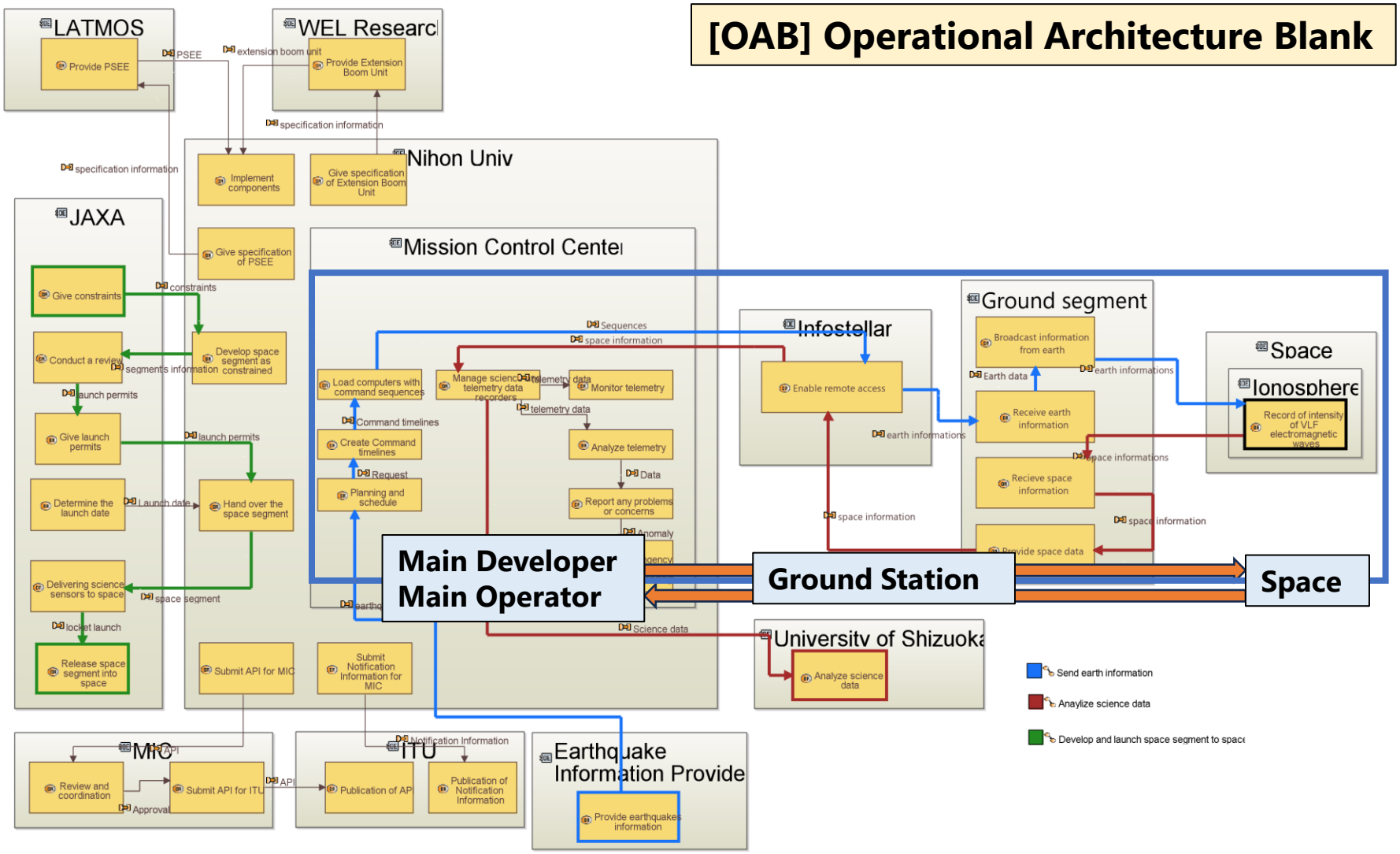
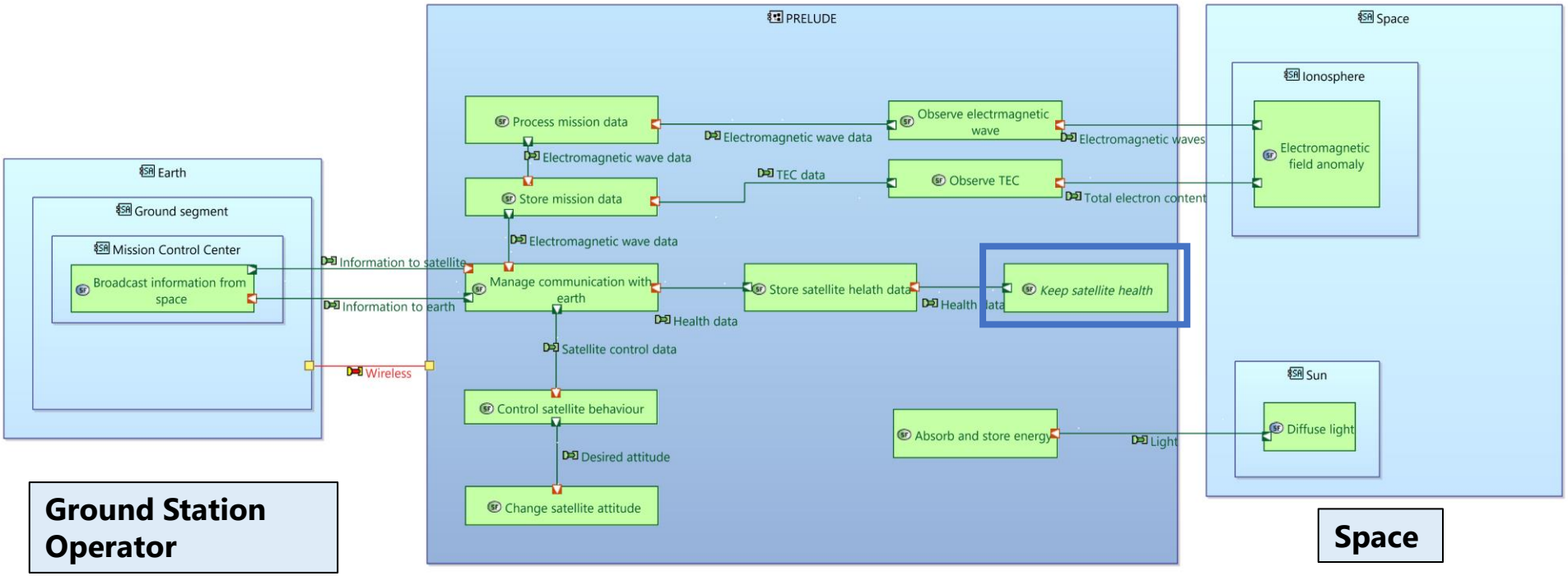


Our Capella models: System Layer

- Expression of functions required for the entire satellite depending on the mission
- Not only the functions required for the mission, but also the functions to maintain the satellite are necessary.

[SAB] System Architecture Blank



Our Capella models: Logical Layer

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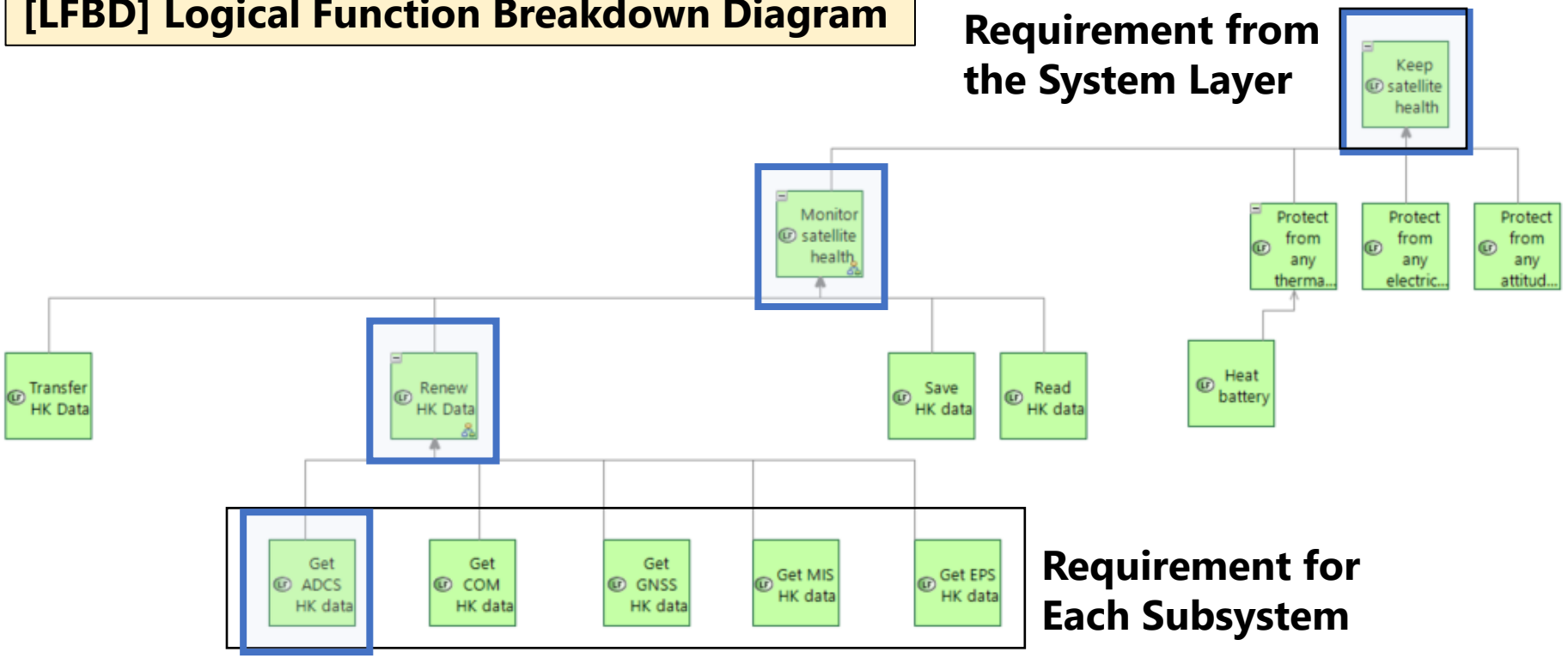
- Example of logical layer analysis with breakdown of system layer requirements.
- The analysis stops at the subsystem level elements and does not mention components.

[LFBD] Logical Function Breakdown Diagram

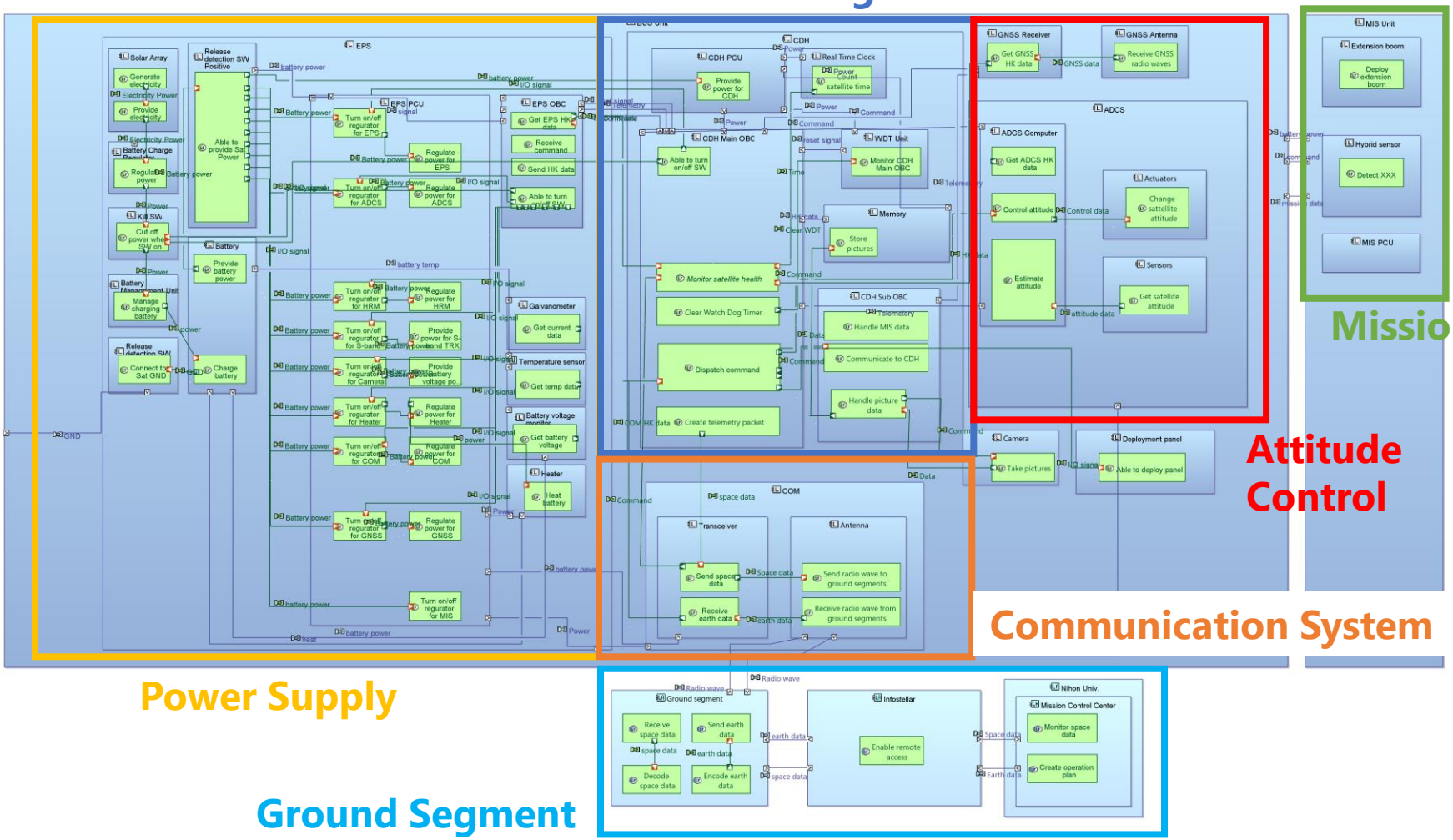


By breaking down the necessary elements for the entire satellite, it is possible to identify the necessary functions of the software without omissions, leading to improved reliability.

Our Capella models: Logical Layer

- You can look at the model of the entire system, or you can focus on individual parts.

[LAB] Logical Architecture Blank



Our Capella models: Logical Layer

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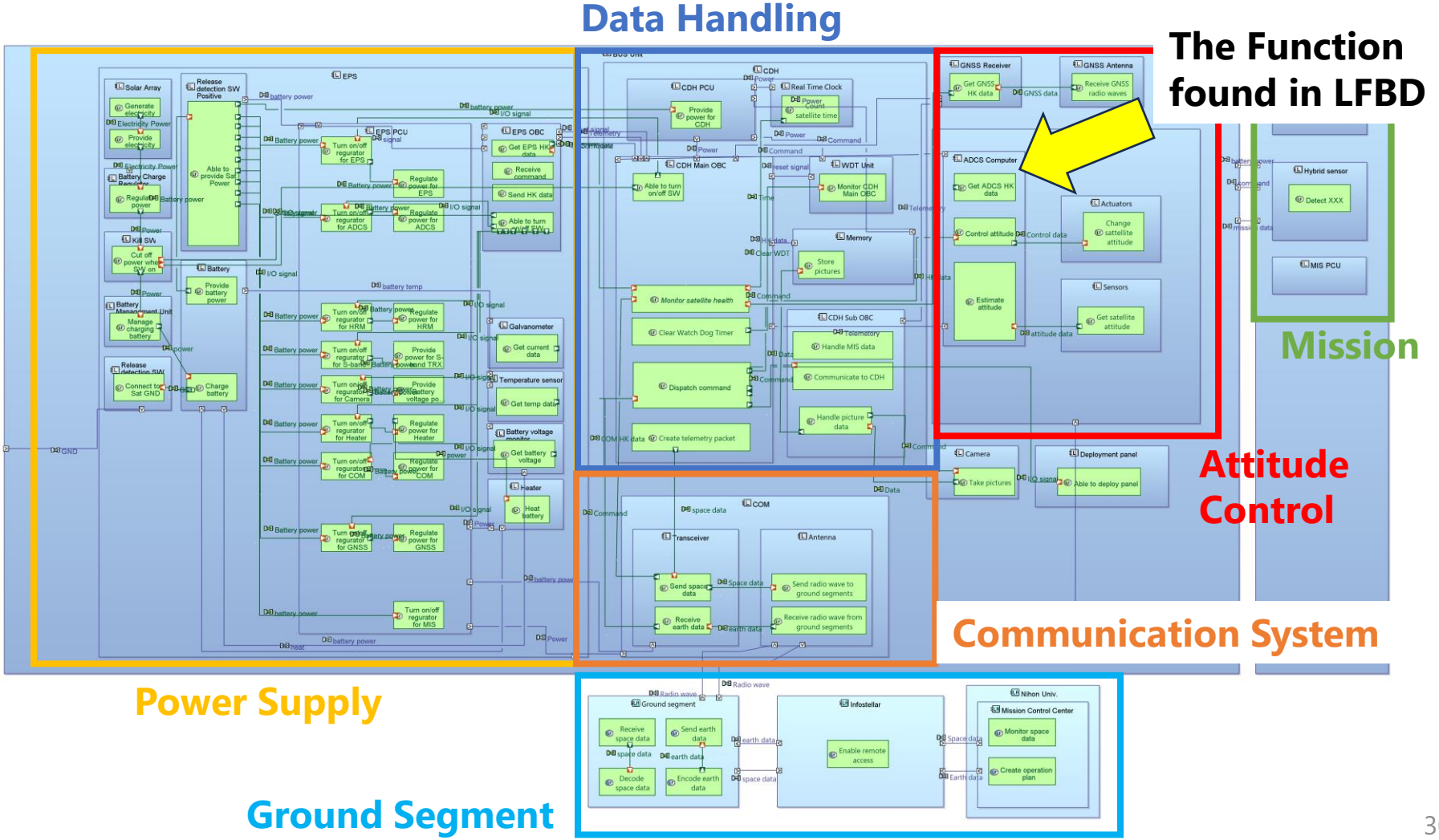
[LAB] Logical Architecture Blank



Keywords in CubeSat software

- We used Capella primarily for software design optimization.
- We consider the following three keywords to be important as indicators of optimization.

- **Reliability**
  - Once the satellite is deployed in orbit, only software can control its behavior.
  - Therefore, reliability is needed in satellite software.

- **Flexibility**
  - To deal with unpredictable events in orbit.
  - Some things you just don't know until you launch them.

- **Reusability**
  - Different satellites share the same basic functions.
  - If common parts can be used, development time can be shortened.

Software architecture of PRELUDE

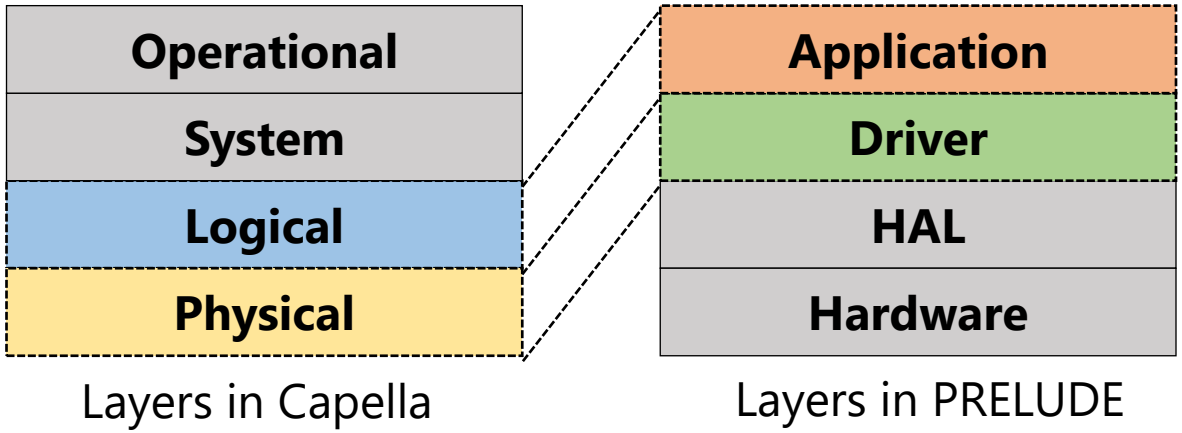
- **Layered architecture** for reuse and maintainability.
- Upper layers are abstracted so that they don't need to change even if hardware changes.

- Application layer is a layer for what the user wants to do.
- Driver layer is a layer for how to do it.

Layer		Objective	Example
Software (S/W)	**Application**	Function satisfies requirements for subsystem	Execute command, Monitor satellite health
	Driver	Function to control components	Write data to memory devices, Communication between other OBC
	HAL	Abstract hardware dependencies	SPI transaction, GPIO

On-board software development using Capella

- **Logical Analysis（LA）**
  - **Compatible with application layer in software**
  - How the system behaves to meet demands
  - Identify requirements for subsystems
- **Physical Analysis（PA）**
  - **Compatible with driver layer in software**
  - How the system will be built
  - Identify requirements for components

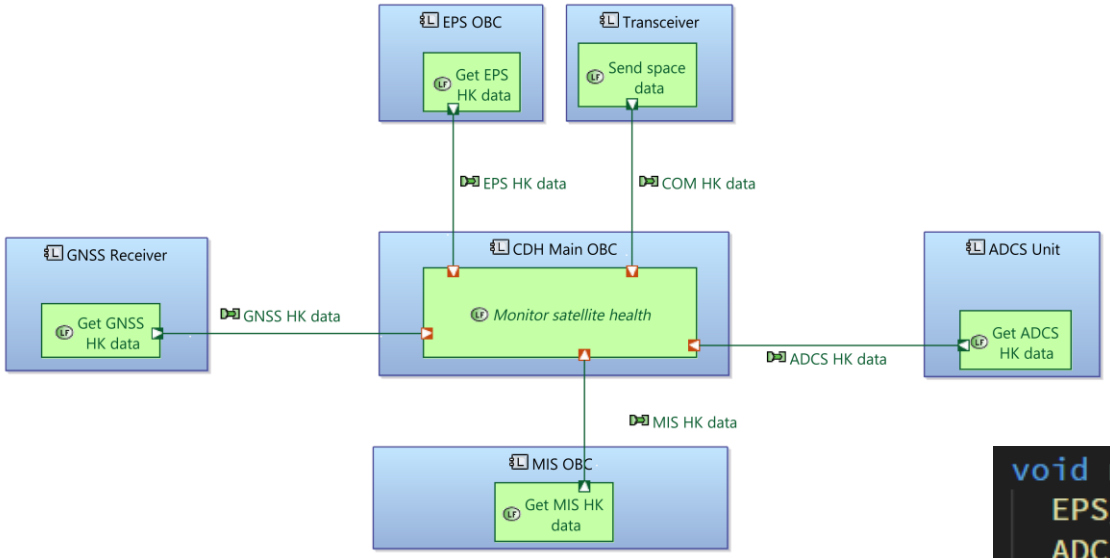


By hierarchizing software, there is no need to change the upper layers even if the lower layers change, thereby improving reusability.

Our Capella models: Logical Layer

- Logical Architecture Blank Diagram focusing only on the acquisition of HK data.
- A program with the same “Function” was created based on this diagram.

[LAB] Logical Architecture Blank




```
void monitor_satellite_health(void) {
  EPS_get_hk(&cdh_all_hk.eps);
  ADCS_get_HK(&cdh_all_hk.adc);
  GNSS_get_HK(&cdh_all_hk.gnss);
  COM_get_HK(&cdh_all_hk.com);
  MIS_get_HK(&cdh_all_hk.mis);
}
```

The same functions as in the model are implemented in the software so that we can understand the software visually.

On-board software development using Capella

1. **Single Command**
   - Command to control satellite movement

2. **Macro Command**
   - A series of operations can be called up from a single command.

Capella Functional Chain

Macro Command

We find Capella and functional chain useful when designing macro commands, reordering single commands, and considering what is optimal.

Today’s contents

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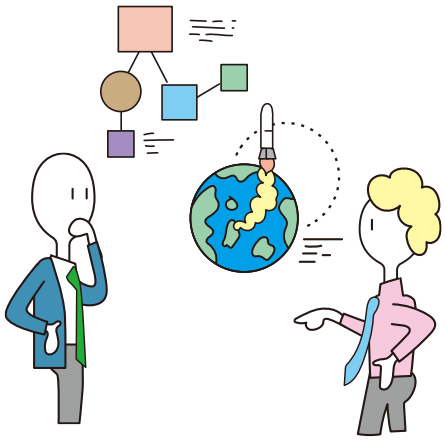
- Introduction of Speakers
- Why we adapted Capella?
  - What are space systems?
  - What are CubeSats?
  - What we hope to achieve with Capella
- Our Capella model
  - About our CubeSat PRELUDE
  - Software design using Capella
- **Conclusion**
  - **What we have achieved with Capella**
  - **Future plans**

What we have achieved with Capella

- **By looking at the model and discussing it, we were able to clarify the requirements for the system.**
  - We could logically derive criteria for success/failure of the system.

- **By deriving the software module partitioning from Capella, the logic of the software design became clear.**
  - The team was able to share the concept of software design.
  - Reliability and reusability of the software were improved.
  - In the future, we would like to apply the Functional Chain concept to software so that we can increase flexibility.



Future plans

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- Now, it is mainly used for software design and success criteria, but in the future, I would like to use it for system design (e.g., for the next satellite).
- I would like to actively utilize Team for Capella, where everyone does the modeling instead of just one person.
  - We would like to make it a common language within the laboratory so that all members can use it.

https://www.obeosoft.com/en/team-for-capella