Enhancing GNSS-reflectometry Earth Observation through a CubeSat Formation

by J. Thoemel[1], M. Drouguet[2], S. Tabibi[3], D. Lederer[4], S. Lambot[4], C. Craye[2]

[1]SpaySys Research Group, University of Luxembourg, Interdisciplinary Centre for Security, Reliability and Trust, Luxembourg
[2]Antenna Group, UCLouvain, Belgium
[3]Geophysics Laboratory, University of Luxembourg, Faculty of Science, Technology and Medicine, Luxembourg
[4]Georadar Research Centre, UCLouvain, Belgium

13th European CubeSat Symposium, Leuven, Belgium

UNIVERSITY OF LUXEMBOURG

University of Luxembourg
Interdisciplinary Centre for Security, Reliability and Trust

- Space Research & Space Labs
    1. LunaLab – analogue facility
    2. Concurrent Design Facility
    3. ZeroG Lab
    4. CubeSatLab – CubeSat integration facility
    5. SatComLab – testbed for satellite communication
    6. 5G Space Lab project

- Interdisciplinary Space Master, courses on
    - technical competences:
        - mission design
        - system engineering
        - satellite communication
        - robotics
        - navigation
    - business competences:
        - entrepreneurship
        - space project management
        - legal aspects

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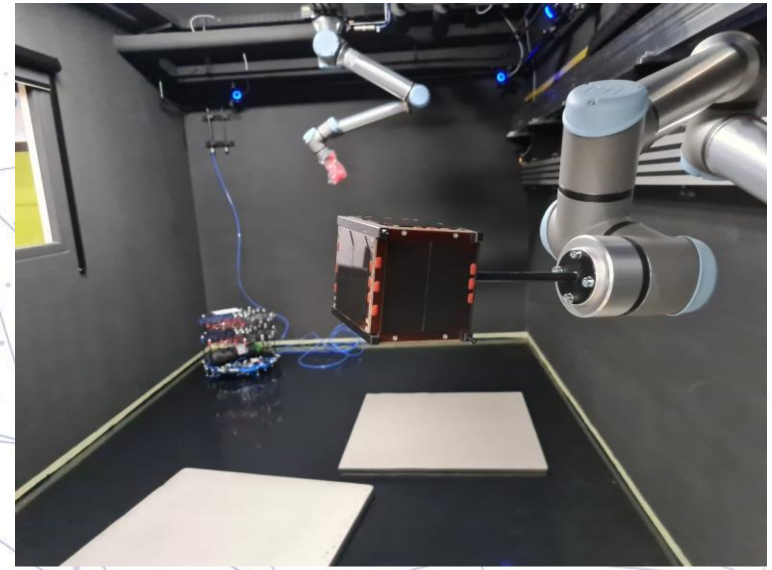
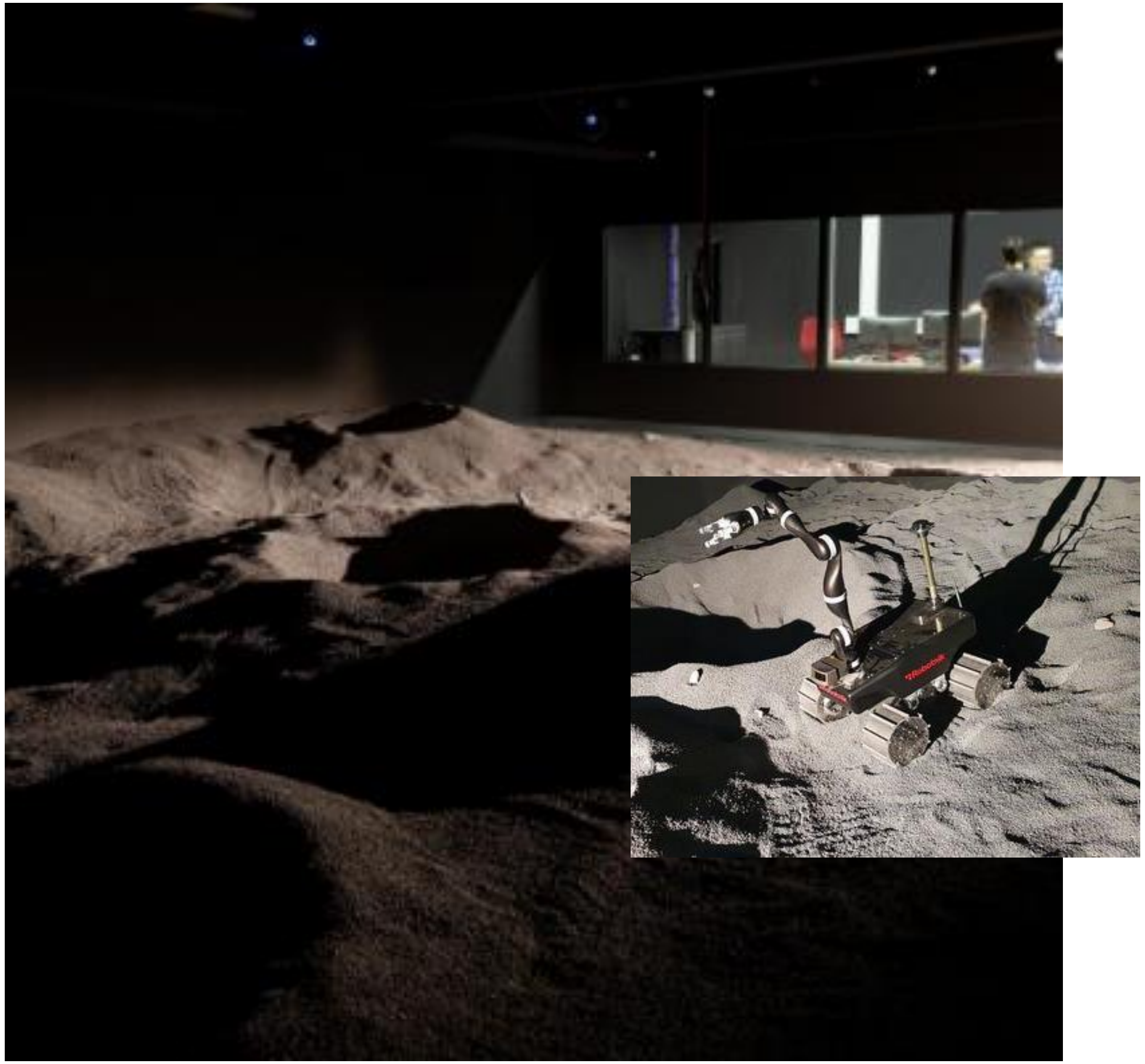
LunaLab & ZeroG Lab

- simulates surface of the Moon:
    - material: regolith/basalt
    - topology: craters
    - lighting: sun, crater shadows

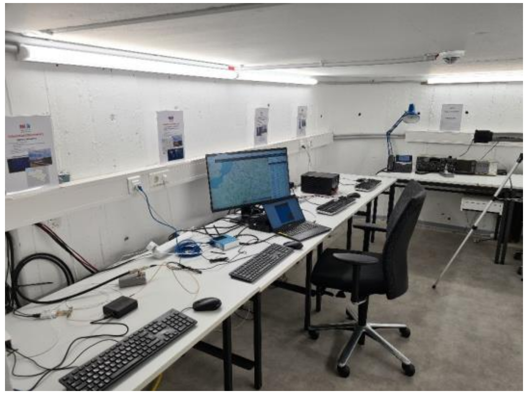
- interaction of two objects in orbit
    - rendezvous
    - space debris grabbing
    - computer vision

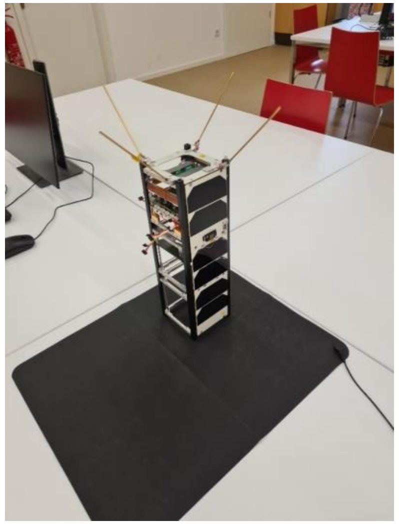




CubeSatLab

- course:
  - basics of low earth orbit space flight and CubeSats
  - design of a CubeSat mission
  - experimenting with the EduSat
- facility:
  - satellite integration room
  - observatory



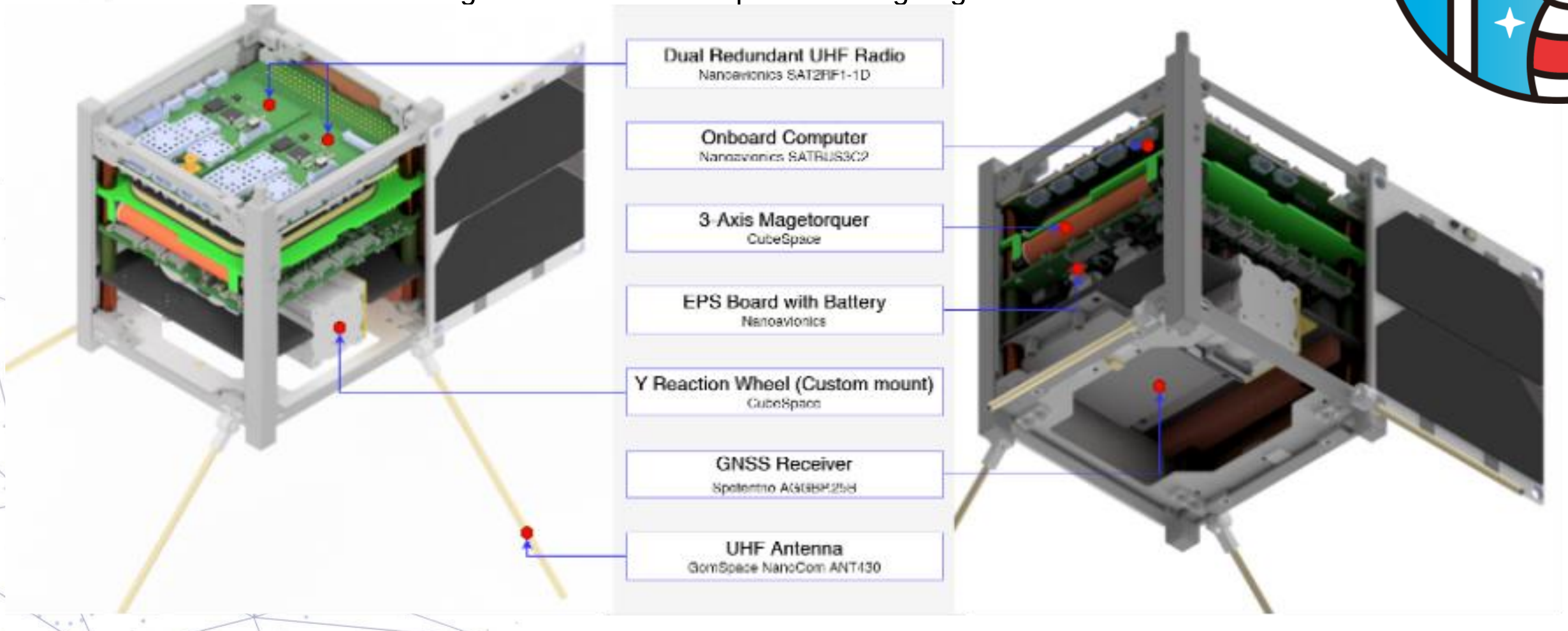


Students designed CubeSat Mission: GoldCrest

determination of soil moisture with:

- 1U CubeSat mission featuring 1 solar panel
- orbit: 6 am SSO
- on-board processing for data reduction
- measurement method GNSS-reflectometry

investigation into business potential ongoing



Friday 26 November 2021, 14:15 – 14:30, Session 10: Cubesat Missions

Global land dampness characterization using reflectometry by students (GOLDCREST): mission and CubeSat design (ID 70)

5G-SpaceLab (Earth-orbiting Scenario)
Objectives and Challenges

Objective:

- **Emulation of LEO CubeSat-based Over-The-Air (OTA) 5G Non-Terrestrial Network (NTN) communication**

To address the challenges:

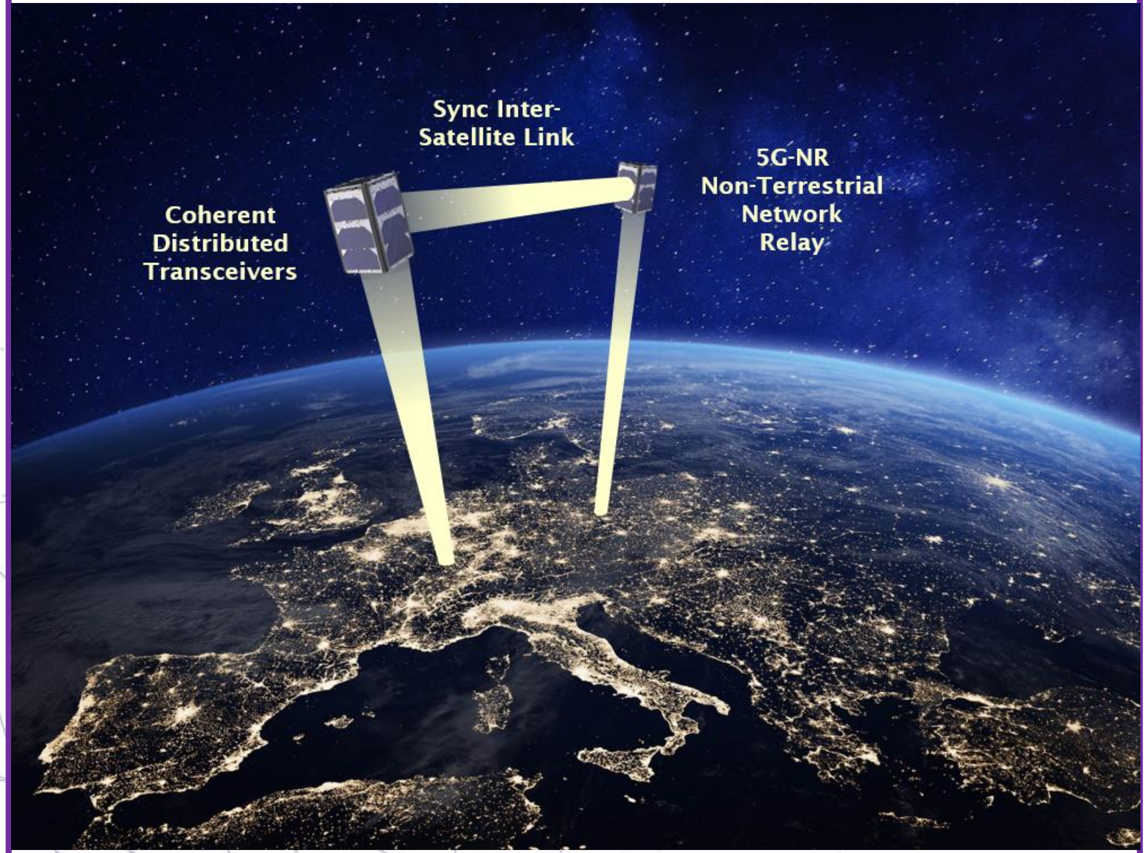
1. **Doppler Shift**
2. **Latency**
3. **Seamless hand-over**

Through the following test scenarios

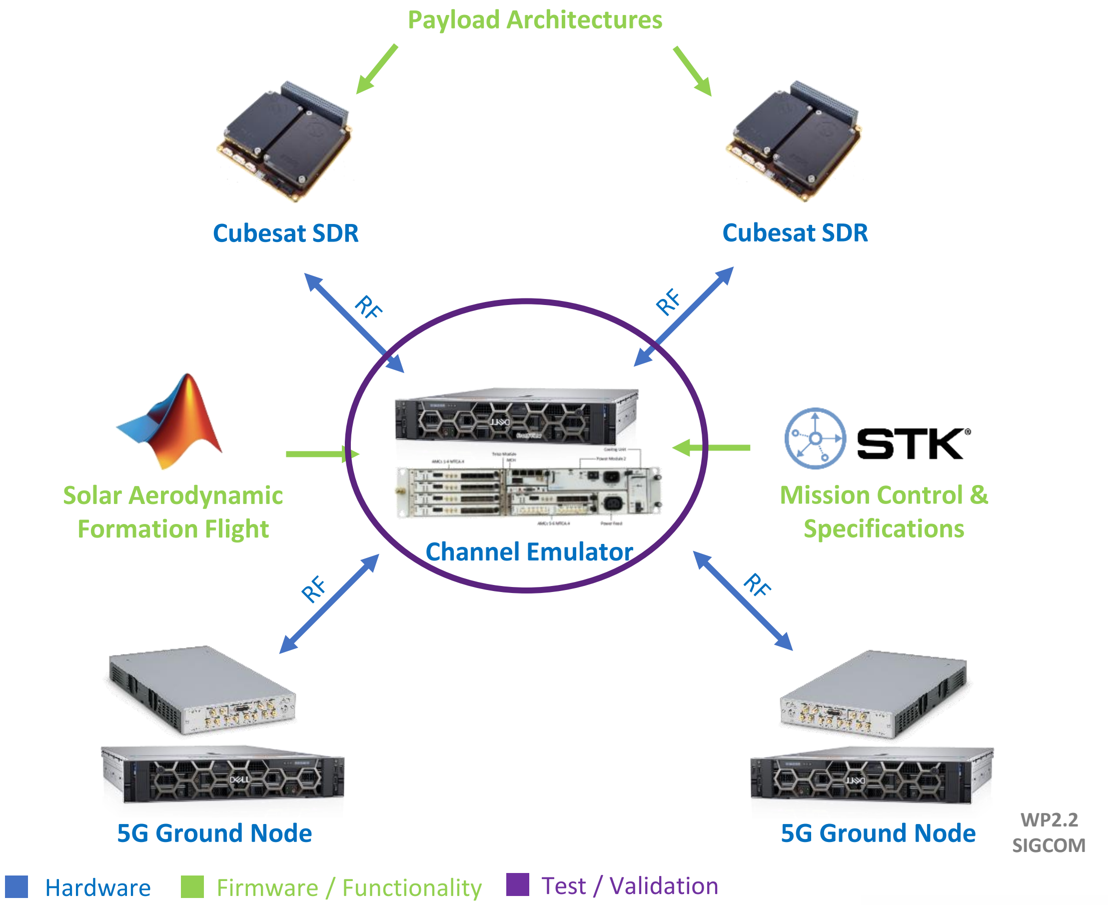
1. **bent-pipe**
2. **node-relaying**
3. **coherent distributed communications**

5G-SpaceLab (Earth-orbiting Scenario)

Conceptual Diagram



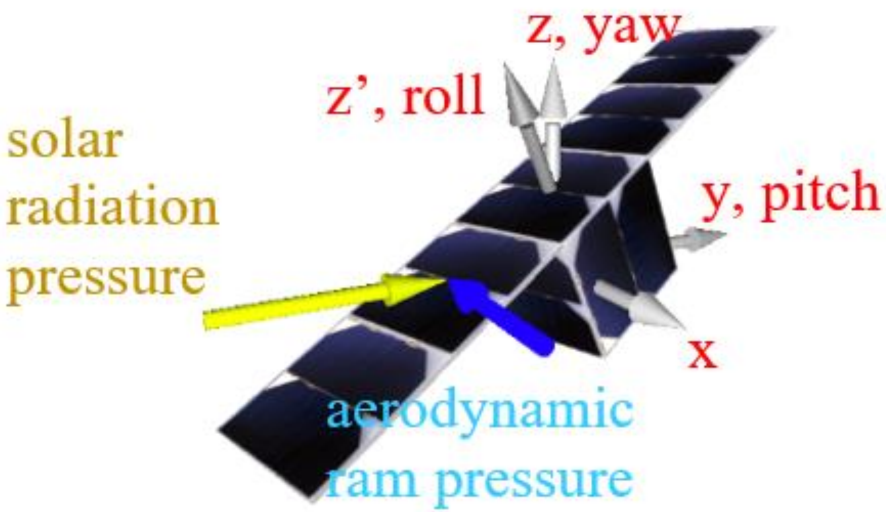
Laboratory Implementation



Challenge: Satellite Flight

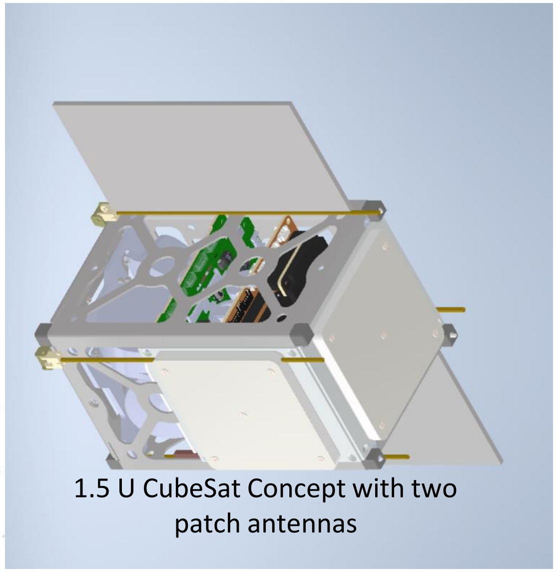
- Problem 1:
  Requirement on a defined distance between the satellites
- Solution:
  Formation Flight, i.e. Multiple satellites with closed-loop control on-board provide a coordinated motion control on basis of relative positions to preserve an appropriate topology for observations[1].

- Problem 2:
  Control and Control Forces
- Solution:
  Aerodynamic and solar-radiation forces combined with an control algorithm

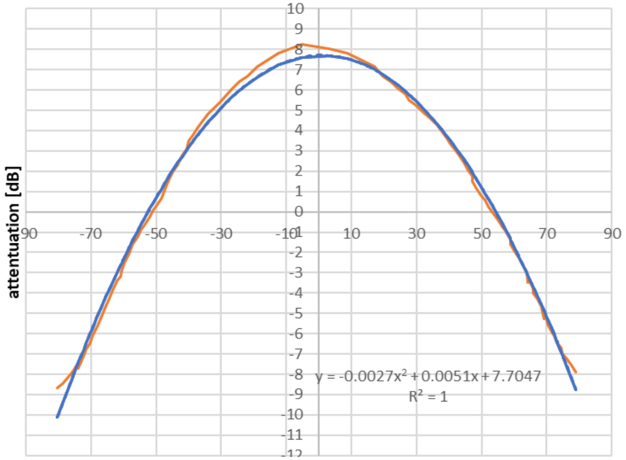


[1]adapted from: K. Schilling, "Mission Analysis for Low-Earth-Observation Missions with Spacecraft Formations," *RTO-EN SCI-231 - Small Satell. Form. Distrib. Surveill. Syst. Des. Optim. Control Considerations*, pp. 1–24, 2011.

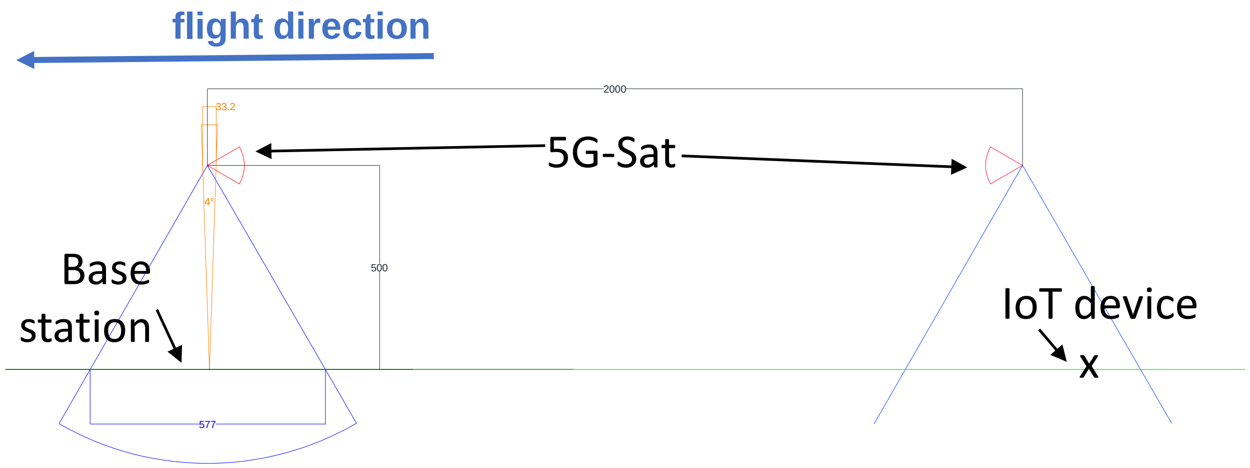
Challenges: communication



1.5 U CubeSat Concept with two patch antennas



antenna pattern GomSpace ANT2000-> 30deg half-cone width

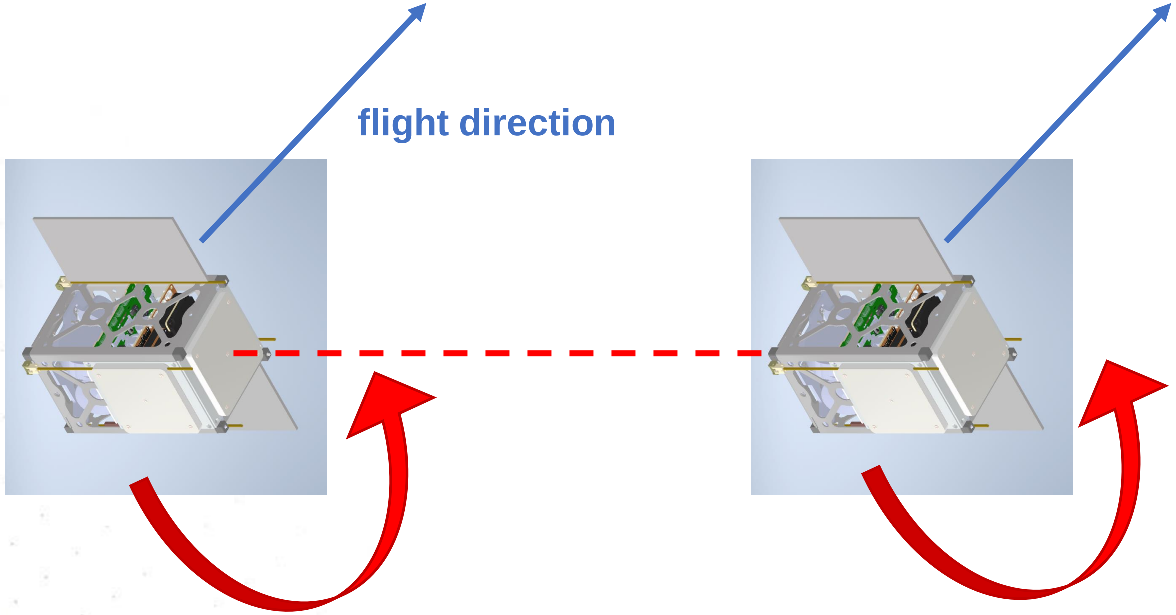


dimensions in km and deg

-> In trailing formation: experiment duration is ~90 s/day

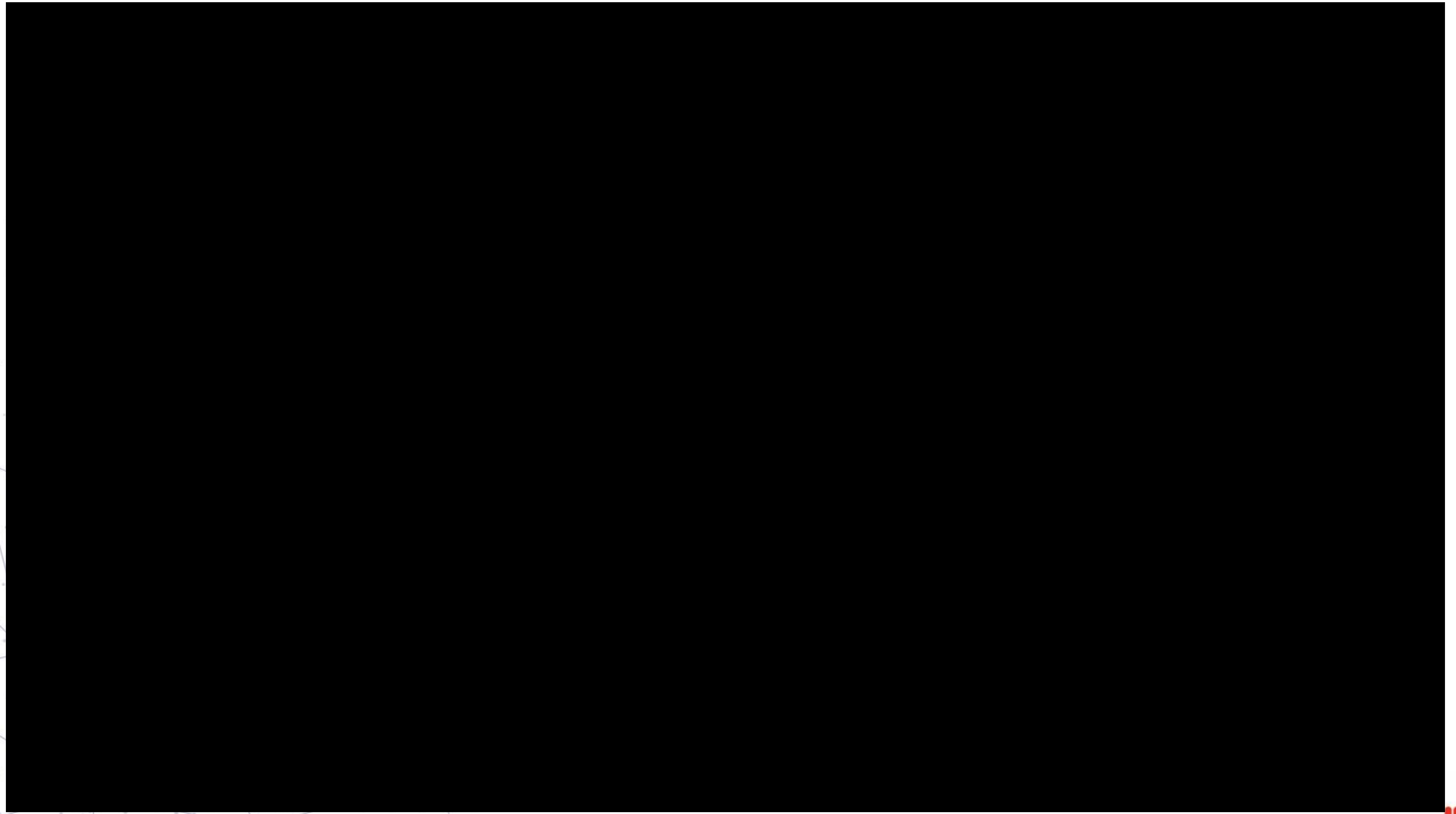
Formation Flight Experimentation Solution

- Side by Side flight with roll/one-axis target pointing



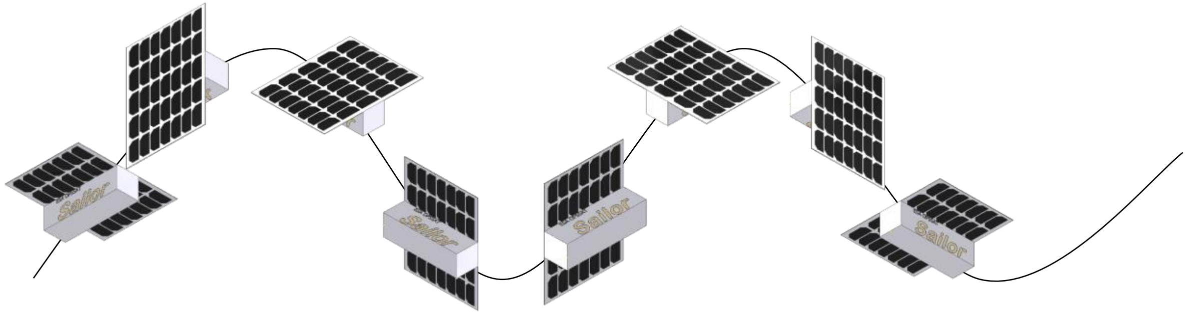
-> experiment duration ~15 min/day

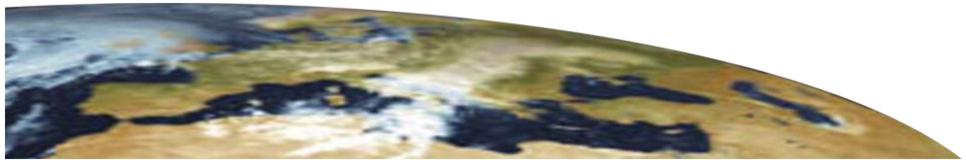
Simulation Results

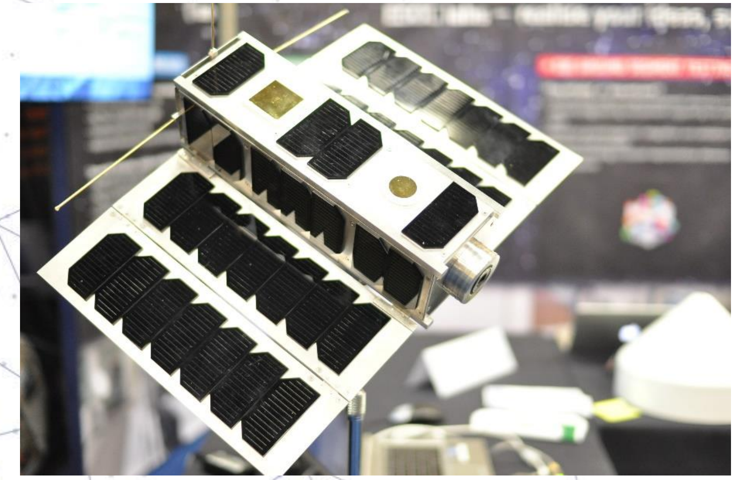


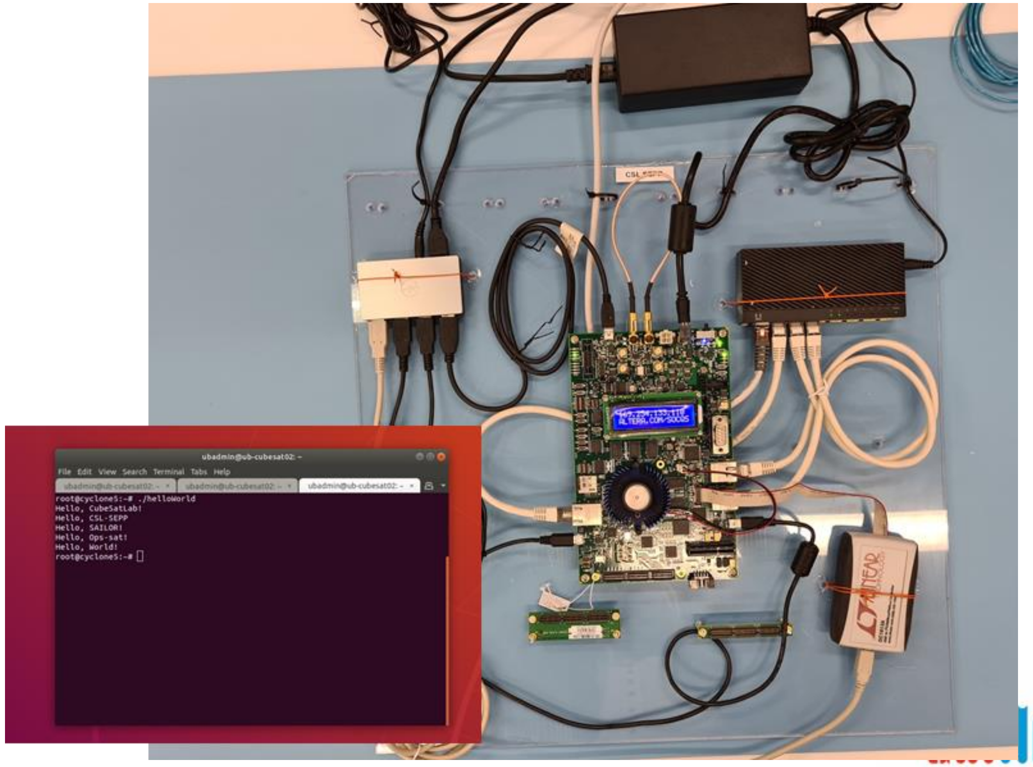
Next: Project Sailor

- **Objective:**
  - **prove formation flight algorithm in-situ**
  - **5G use case as reference**
- **Means:**
  - **ESA Opssat**
  - **combination real satellite-virtual satellite**
- **Status:**
  - **Experiment approved**
  - **ESA OSIP Idea accepted**
  - **cosmos code in upgrading**
  - **Opssat payload computer engineering model established**









Concluding Remarks

1. Uni.lu researches formation flight

Thank you!
Do you have any questions?

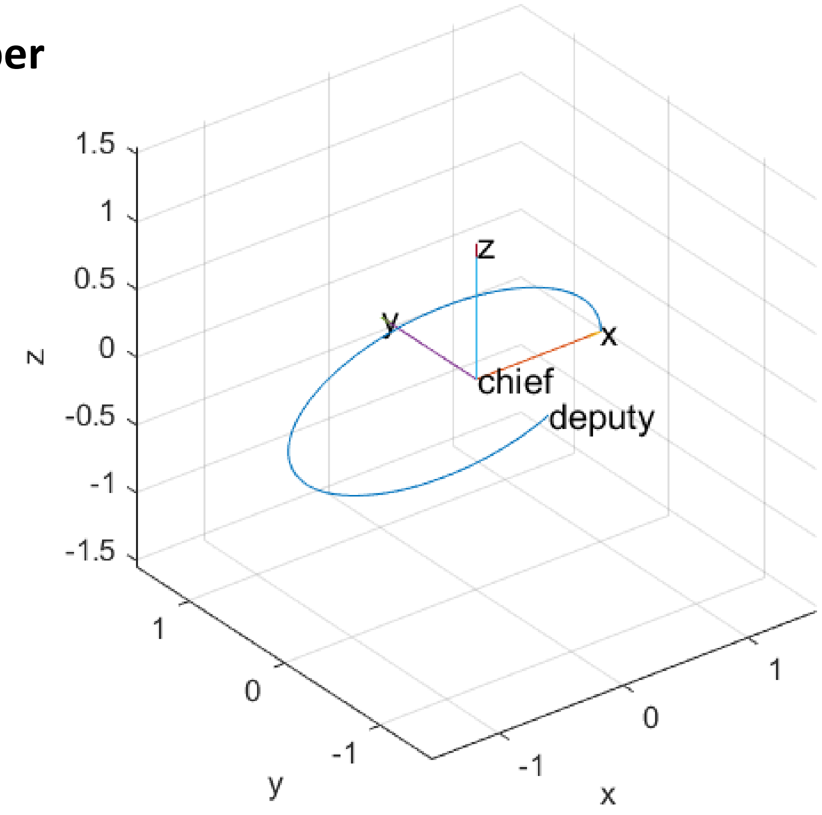
Speaker: Jan Thoemel

University of Luxembourg
Interdisciplinary Center for Security Reliability and Trust

Derivation Formation Flight Physics I

- from Kepler body problem
- given a local coordinate system (figure)
- the following equations can be derived for each formation member

$$\ddot{x} - 2\omega\dot{z} = 0$$
$$\ddot{y} + \omega^2 y = 0$$
$$\ddot{z} - 2\omega\dot{x} - 3\omega^2 z = 0$$



- Hill-Clohessy-Wiltshire equation
- set of ordinary differential equation for
  - three spatial coordinates: x,y,z
  - each formation flight member satellite
- right-hand-side is zero -> no forces/propulsion applied

Derivation Formation Flight Physics II

analytical solution for Hill-Clohessy-Wiltshire equation, deputy satellite:

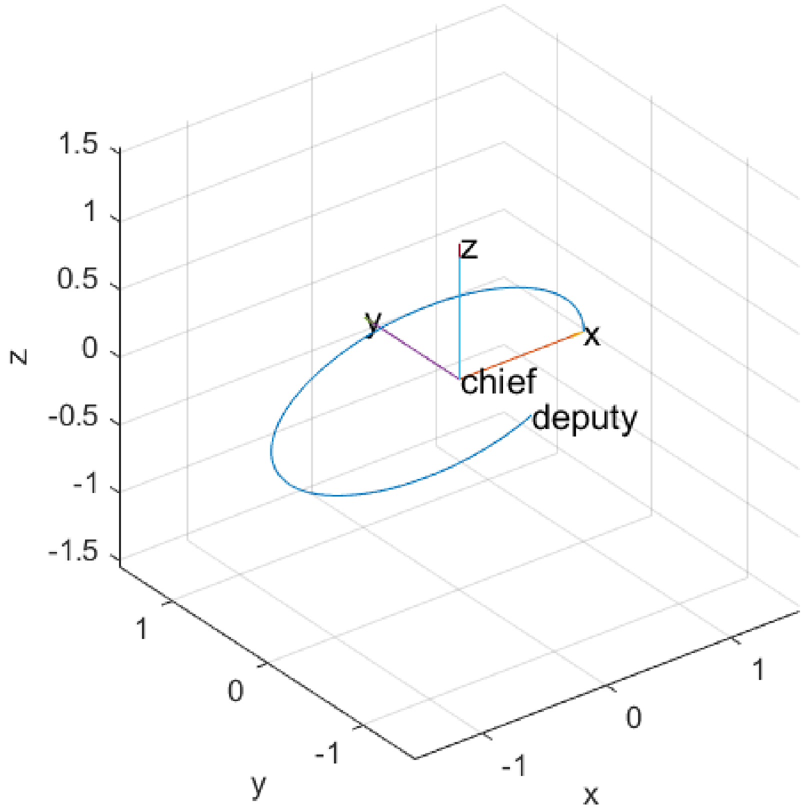
$$x(t) = -3C_1\omega t + C_2\cos(\omega t) + C_3\sin(\omega t) + C_4$$
$$y(t) = C_5 sin(\omega t) + C_6 cos(\omega t)$$
$$z(t) = 2C_1 + C_2 sin(\omega t) + C_3 cos(\omega t)$$

constants:

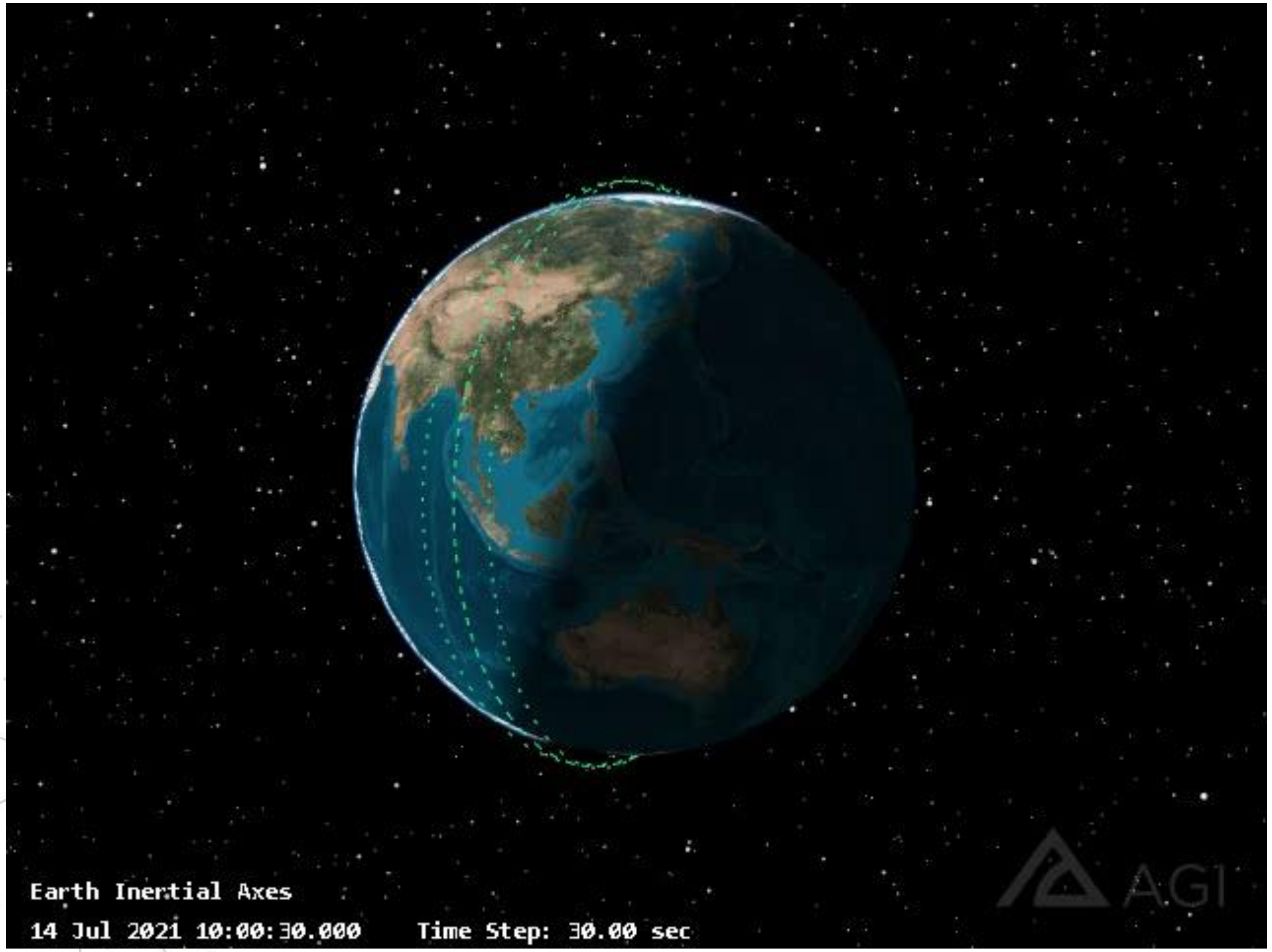
$$C_1 = \frac{u(0)}{\omega} + 2z(0)$$
$$C_2 = \frac{w(0)}{\omega}$$
$$C_3 = -3z(0) - \frac{2v(0)}{\omega}$$
$$C_4 = x(0) - \frac{2w(0)}{\omega}$$
$$C_5 = \frac{v(0)}{\omega}$$
$$C_6 = y(0)$$

initial conditions:

$$x(0) = 1$$
$$y(0) = 0$$
$$z(0) = 0$$
$$u(0) = 0$$
$$v(0) = 0$$
$$w(0) = \omega/2$$



Formation


Earth Inertial Axes
14 Jul 2021 10:00:30.000
Time Step: 30.00 sec
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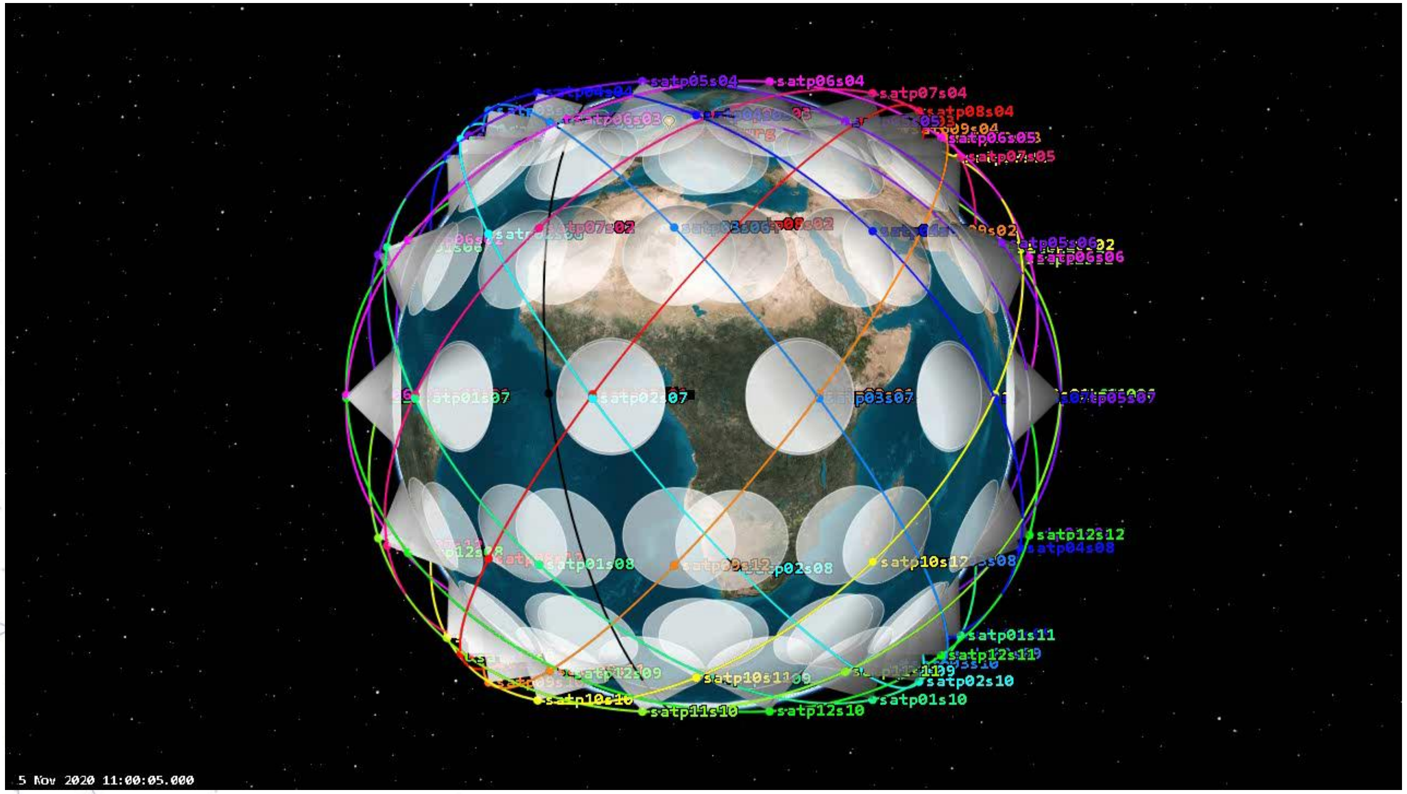
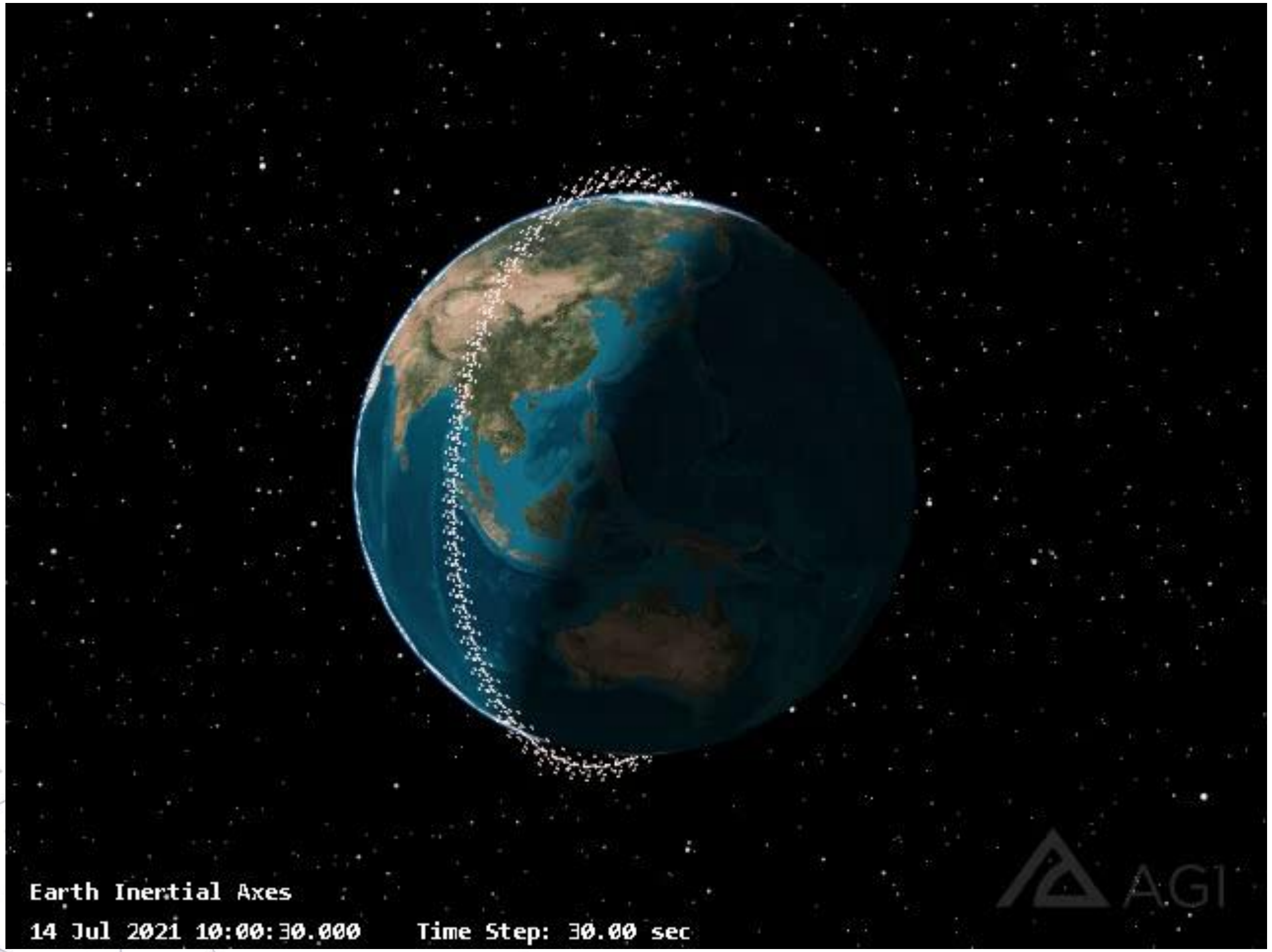
Mega-Constellation: Definition

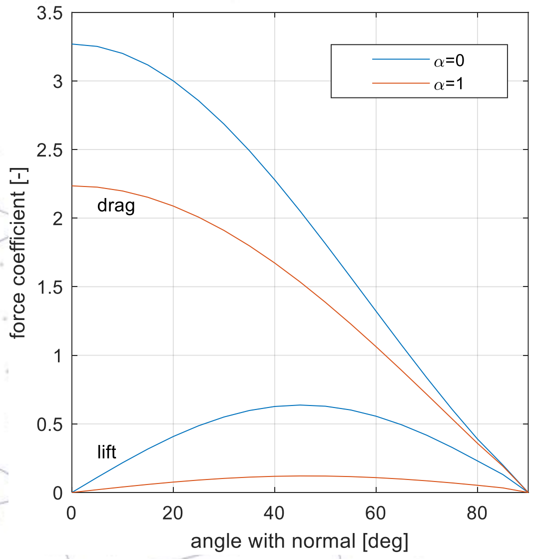


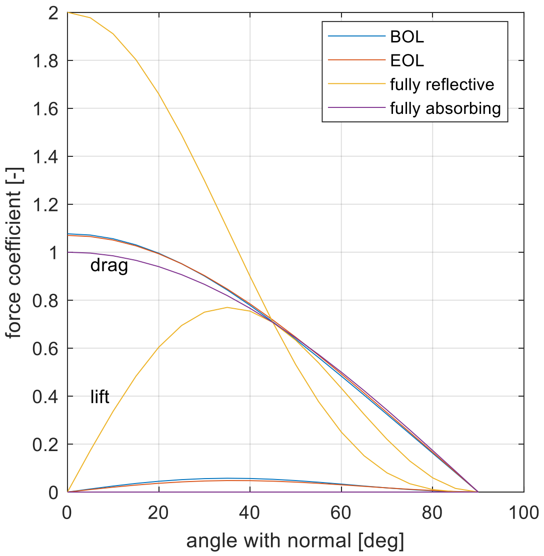
Flock/Swarm/Cluster



State-of-the-Art

1. **aerodynamics are only rudimentarily used for orbit control, e.g. for Mars Express' aero-breaking and Planet Inc.'s constellation maintenance**
2. **full 3-axes aerodynamic control is investigated only theoretically by Leonard[2], Sedwick[3], Ivanov[4], Traub[5], and others**
3. **solar radiation pressure, known to be of similar magnitude as aerodynamic forces, is only considered as disturbance not as control force**





Definitions[1]

- Distributed system of similar spacecraft cooperating to achieve a joint goal without fixed absolute or relative positions**: Flock, e.g. QB50**
- Several satellites flying in similar orbits without control of relative position organized in time and space to coordinate ground coverage: **Constellation, e.g. PlanetLabs**
- Multiple satellites with closed-loop control on-board provide a coordinated motion control on basis of relative positions to preserve an appropriate topology for observations: **Formation/Swarm/Cluster, e.g. NetSat**

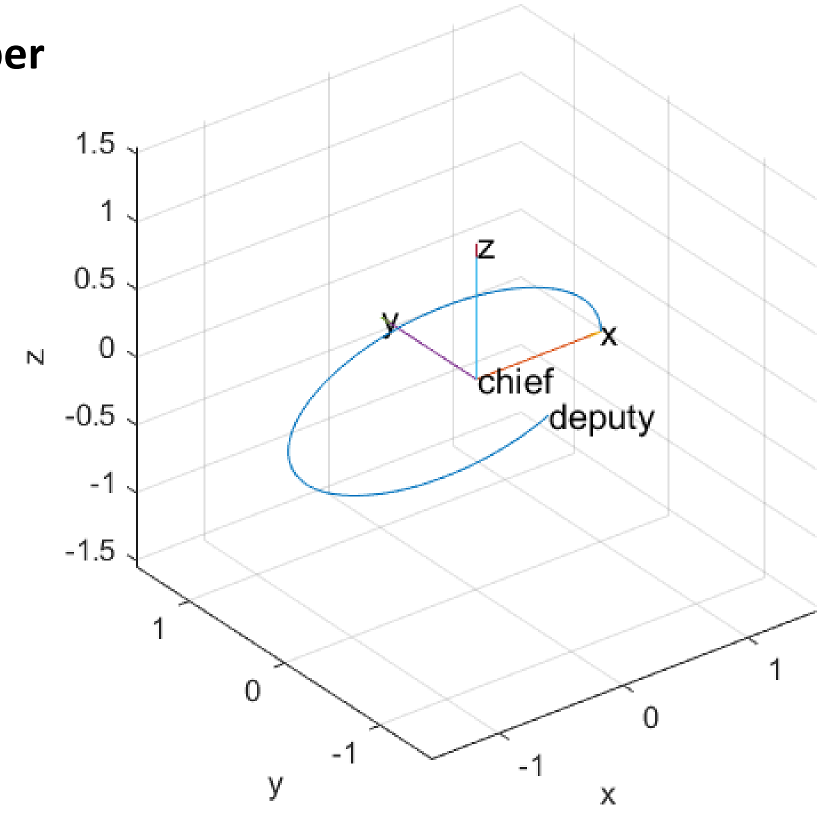
- **Autonomy:** a technical system reacts to disturbances without human intervention
- **Solar-Aerodynamic Flight:** the use solar radiation pressure and ram pressure of the residual atmosphere to control the orbit

[1]adapted from: K. Schilling, “Mission Analysis for Low-Earth-Observation Missions with Spacecraft Formations,” *RTO-EN SCI-231 - Small Satell. Form. Distrib. Surveill. Syst. Des. Optim. Control Considerations*, pp. 1–24, 2011.

Governing Equations

- from Kepler body problem
- given a local coordinate system (figure)
- the following equations can be derived for each formation member

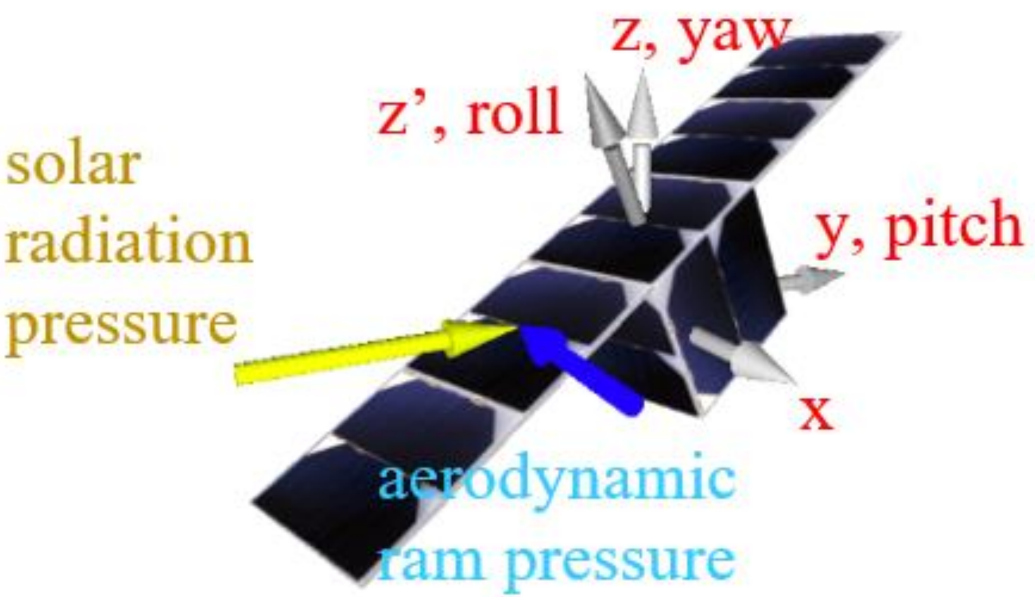
$$\ddot{x} - 2\omega\dot{z} = 0$$
$$\ddot{y} + \omega^2 y = 0$$
$$\ddot{z} - 2\omega\dot{x} - 3\omega^2 z = 0$$

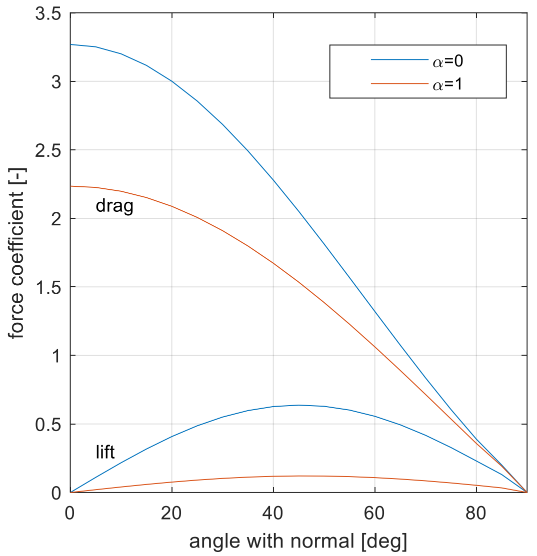


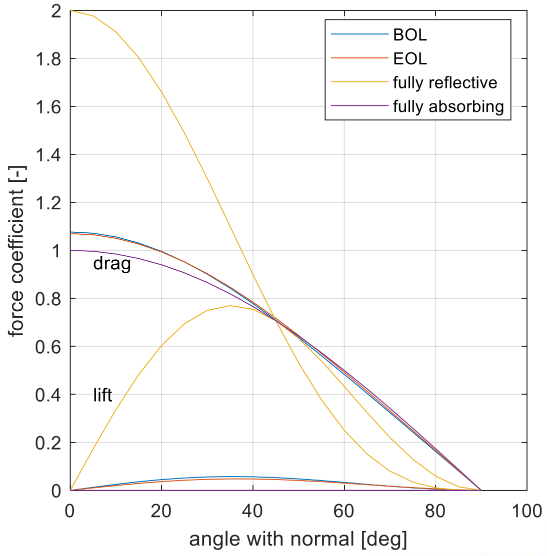
- Hill-Clohessy-Wiltshire equation
- set of ordinary differential equation for
  - three spatial coordinates: x, y, z
  - each formation flight member satellite
- right-hand-side is zero -> no forces/propulsion applied

Solar-aerodynamic Forces

- from Kepler body problem
- given a local coordinate system (figure)
- the following equations can be derived for each formation member







Formation Flight Modes

- **Deployment**
  - **satellites are co-located after launch and move to their formation location**
  - **addressed in:** J. Thoemel and T. van Dam, “Autonomous formation flight using solar radiation pressure,” *CEAS Sp. J.*, 2021.

- **Maintenance**
  - **maintain location in formation under influence of disturbances**
  - **subject of this research**

- **Reconfiguration**
  - **formation geometry changes for instance to change observation characteristics**
  - **coming soon**