ROSpace: a mission simulator for CleanSpace One and beyond

Christophe Paccolat
Christian Lanegger
Michael Pantic

Overview

- CleanSpace One
- Rospace – Requirements & Framework
- Evaluation of Simulation Toolkits
- Layout of the Physics Engine
- Validation of Orbit and Attitude Propagation

Our Mission

Clean Space One

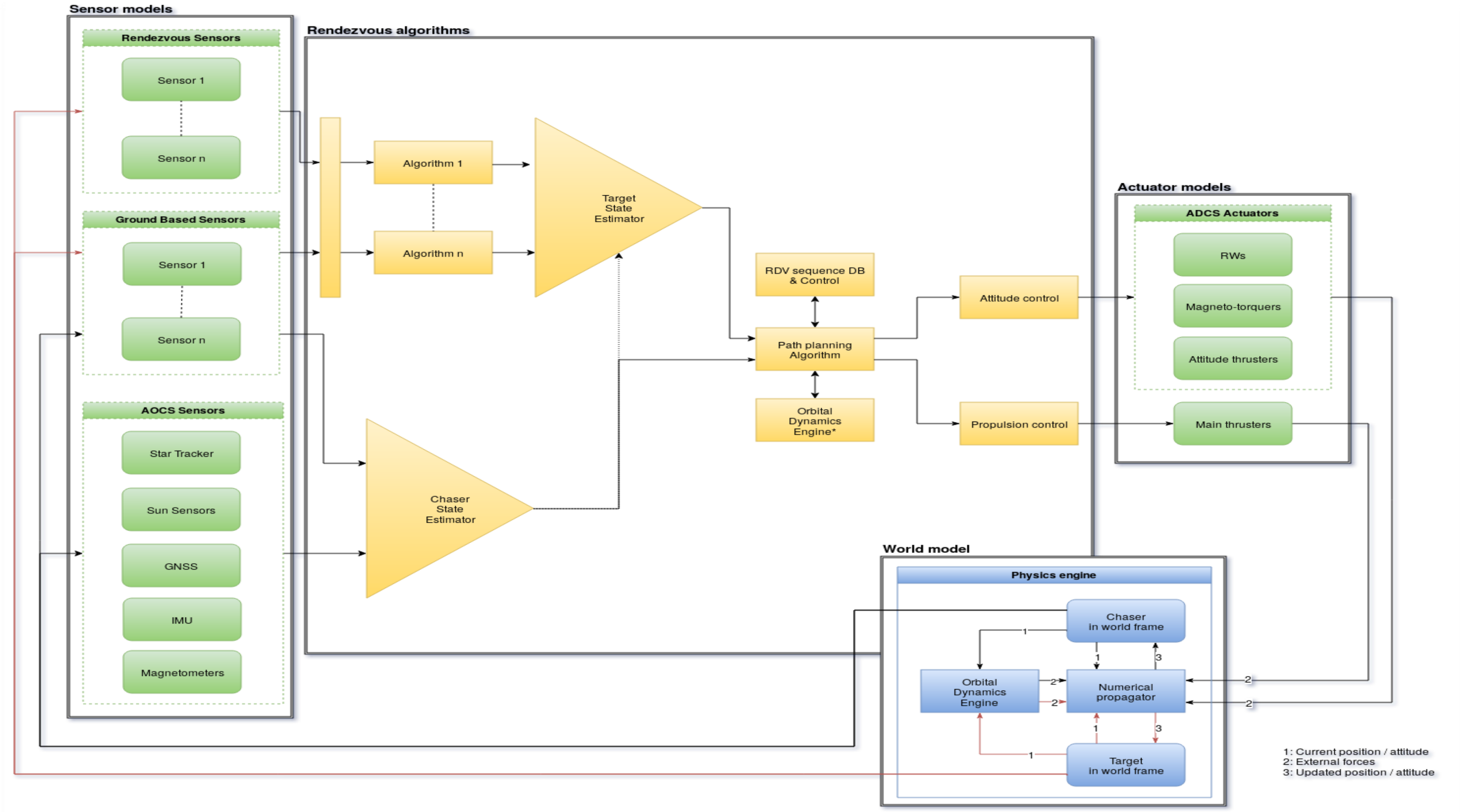
- Capture and de-orbit SwissCube
  - → increase awareness and responsibility in regard to orbit removal
  - → demonstrate technologies needed for ADR
- Challenges:
  - → high tumbling rate
  - → uncooperative rendezvous

ROSpace Simulator

ROSpace – Requirements

- ***Requirement 1:*** Publishable & Reproducible
- ***Requirement 2:*** Verification
- ***Requirement 3:*** Model Accuracy
- ***Requirement 4:*** Customizable

ROSpace – Simulation Framework



Evaluation of Simulation Toolkits

Toolkit – Evaluation Criteria

- ***Criterion 1:*** Completeness
- ***Criterion 2:*** Flexibility
- ***Criterion 3:*** User-Friendliness

Options for Capture Simulator

- Software with GUI: STK (commercial), GMAT (open-source)

  → strength in high-level mission simulation (orbital maneuvers, coverage planning)

- Software libraries: 42 (C++), Basilisk (C++), TUDAT (C++), OREKIT (Java)

  → which one to chose?

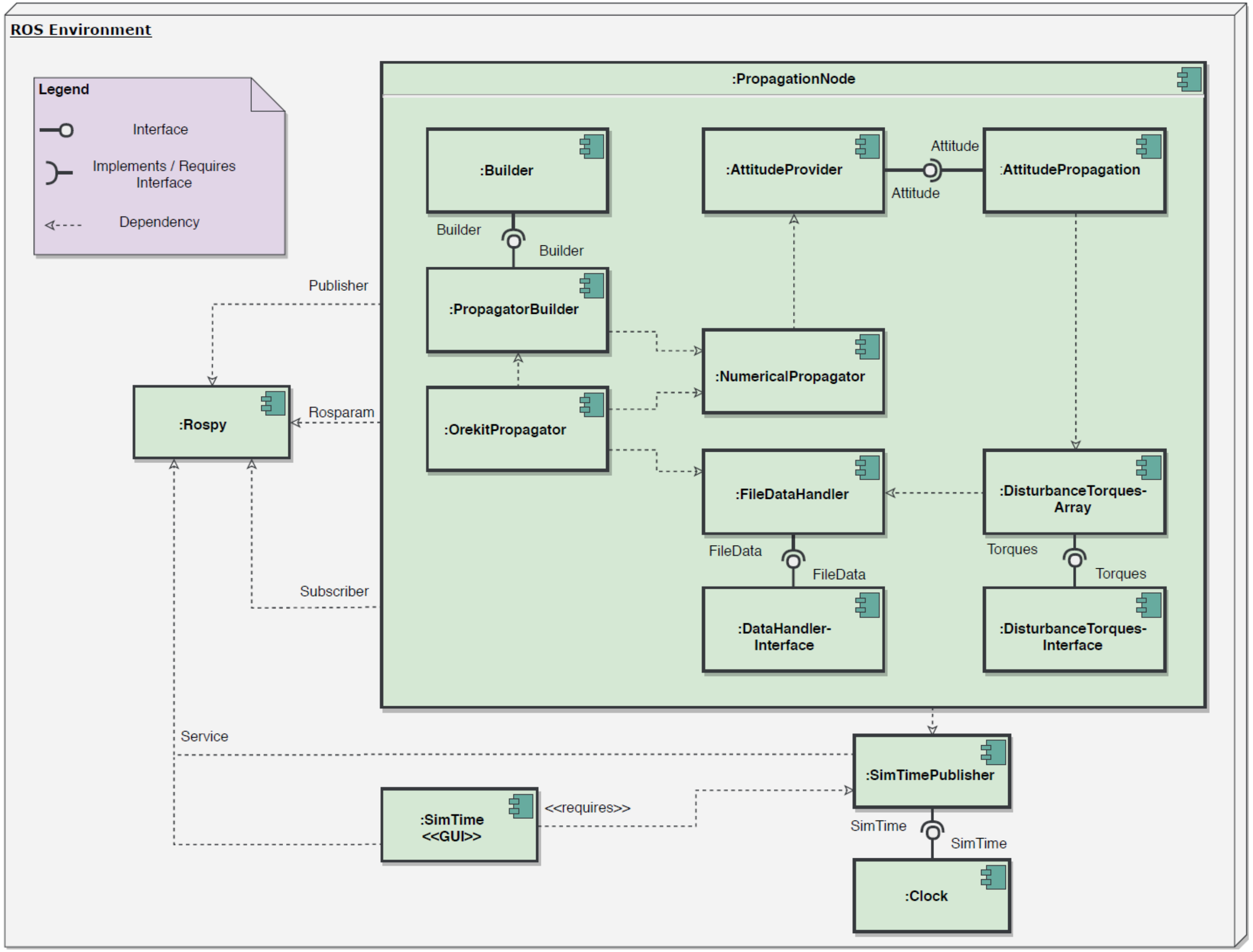
Options for Capture Simulator

	42	Basilisk	TUDAT	OREKIT
+	• C++ • Multi-body dynamics • Contact forces • Attitude dynamics	• C++ • Actuator & sensor models • Attitude dynamics	• C++ • User-Friendly (tutorials)	• Validated & successfully tested • Well documented • Variety of sophisticated models
-	• Deprecated atmosphere model • Only low coefficient gravity models • No tide models	• Documentation • Only general purpose models listed	• Simple radiation pressure model • Not tested in real world • No attitude dynamics	• Java • No attitude dynamics

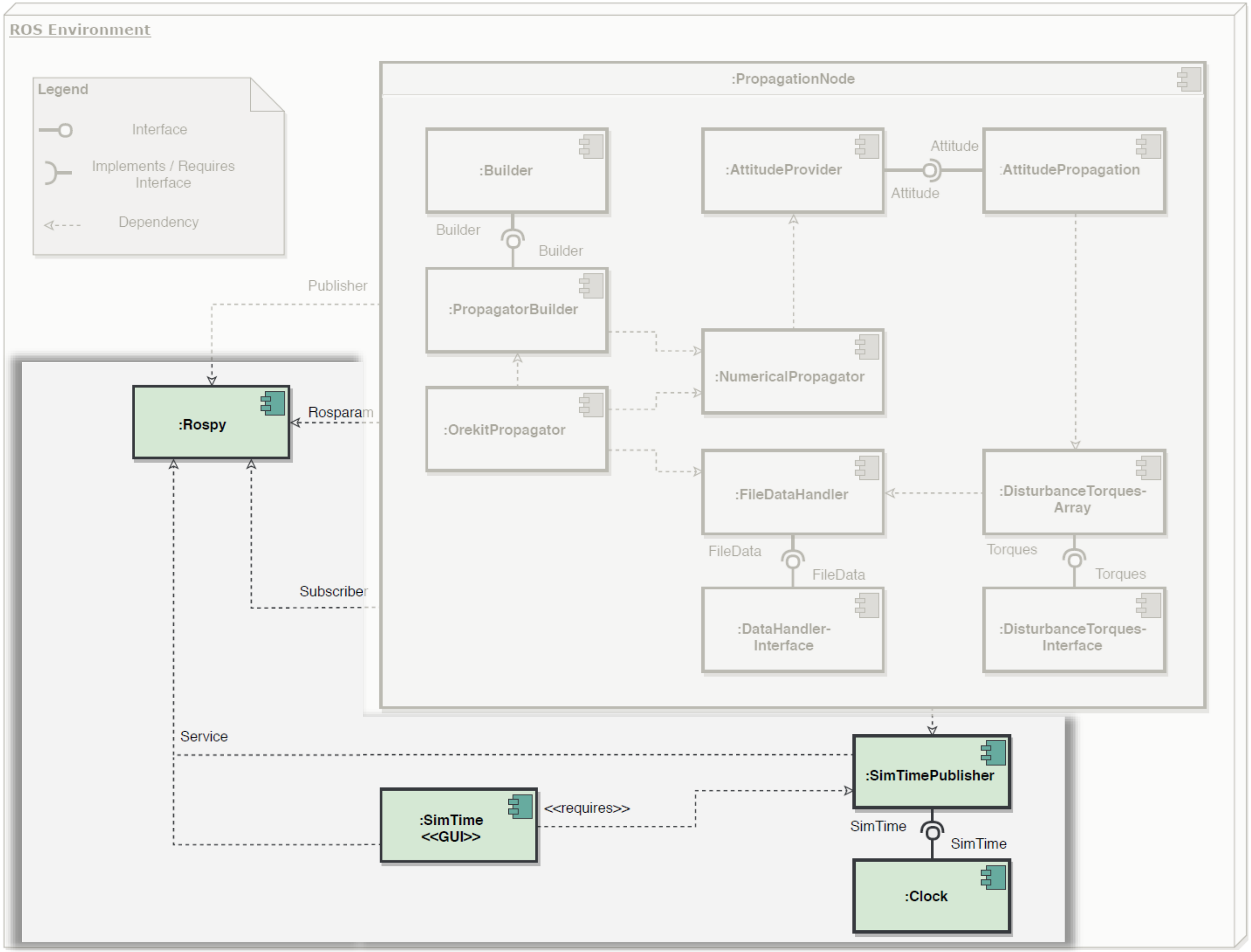
Layout of the Physics Engine

General Layout

- Engine embedded in ROS environment
- `:Rospy` provides communication tools between ROS-nodes
- Clock interface separated from PropagationNode

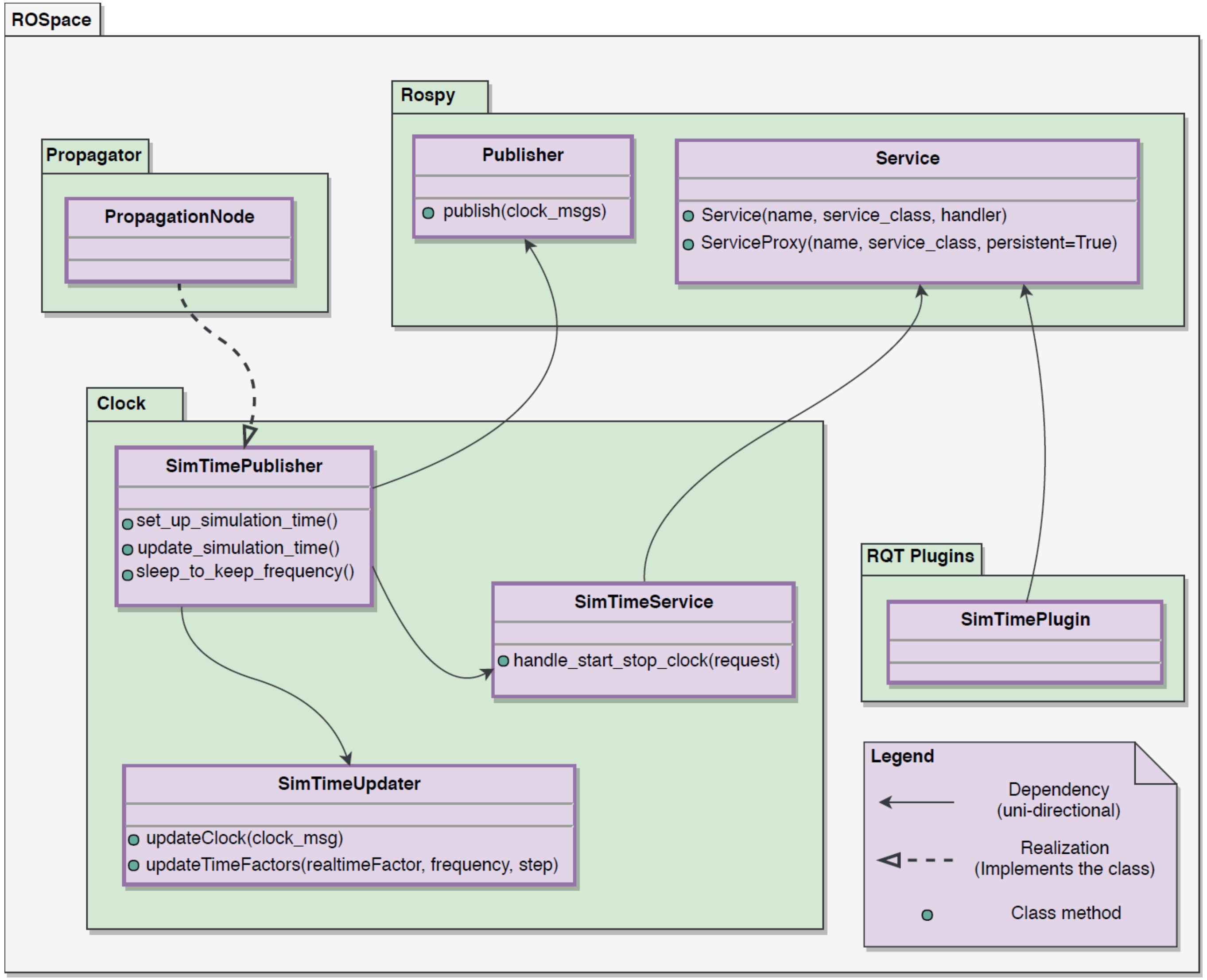


Clock Library

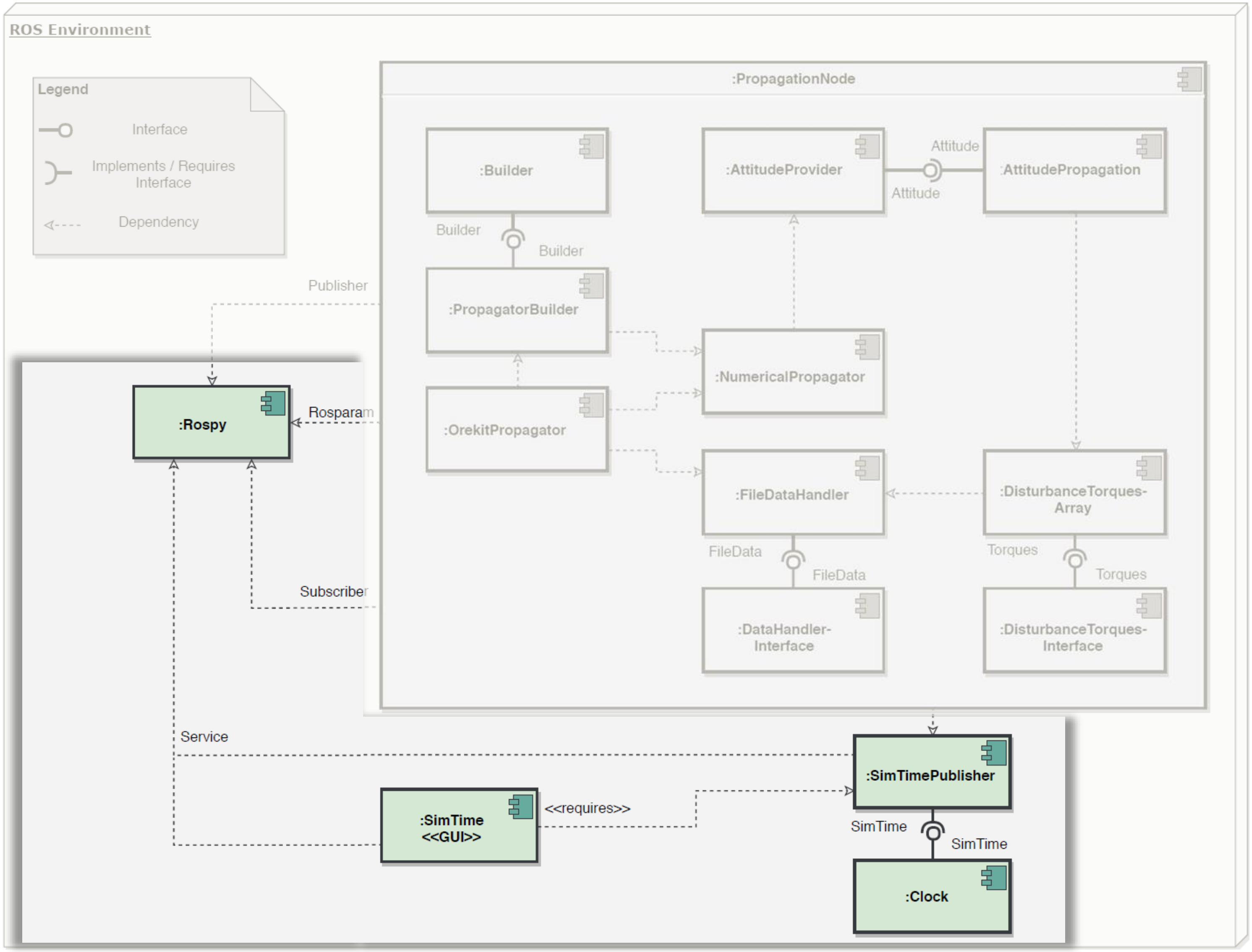


Clock Library

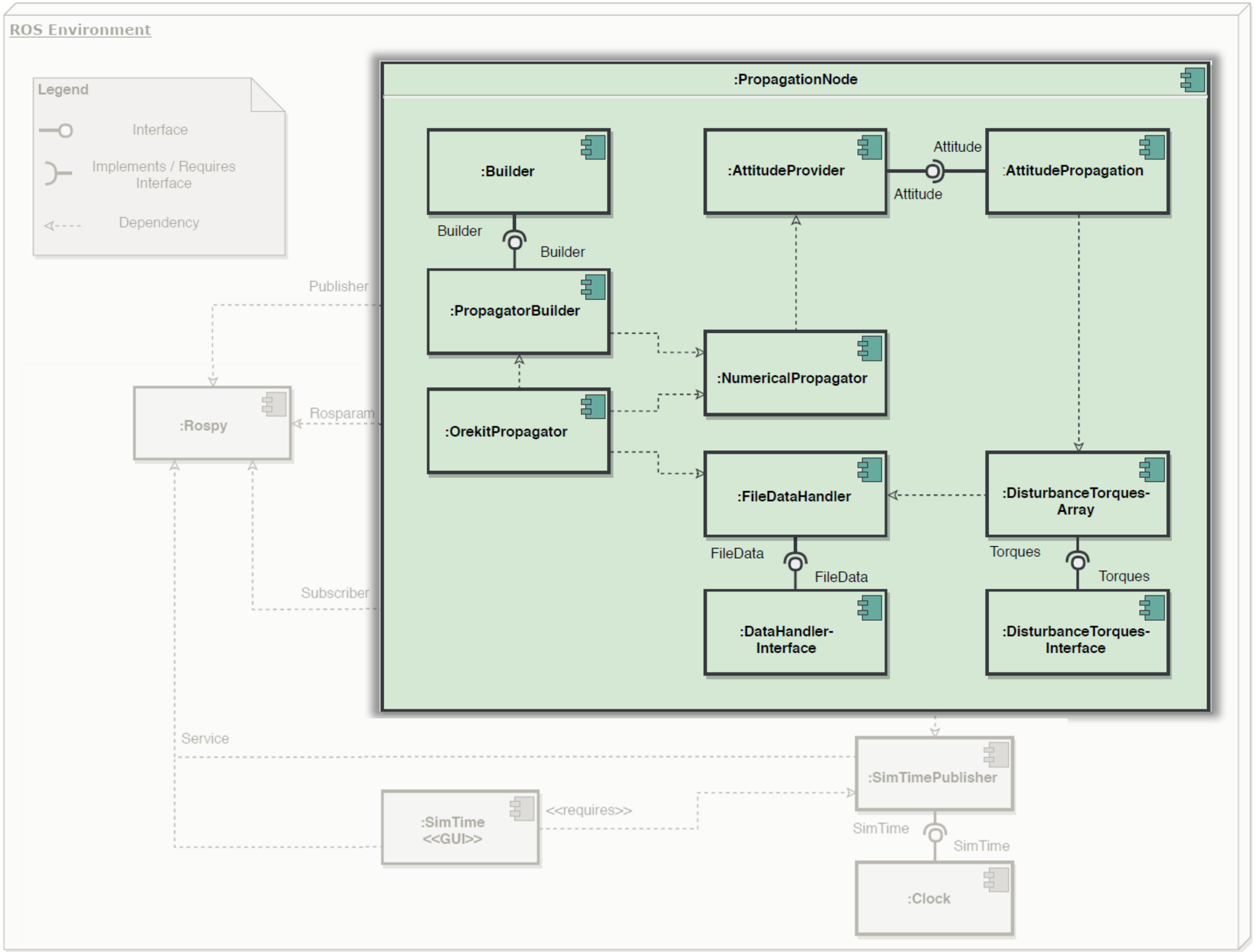
- Handles time based on commands from first caller class
- Multiple calls from different nodes result into error
- Time can be manipulated with developed GUI



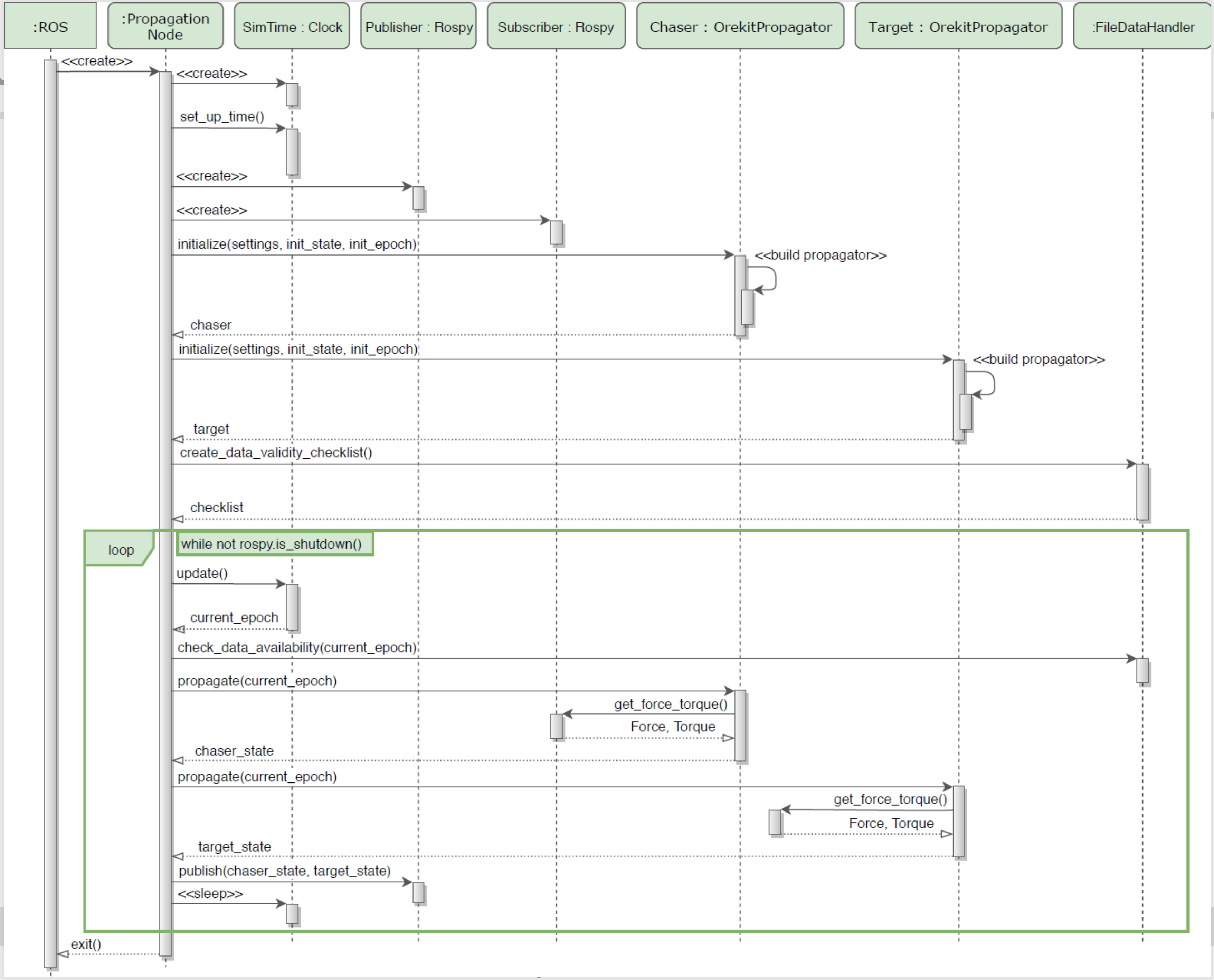
Clock Library



Propagation Node

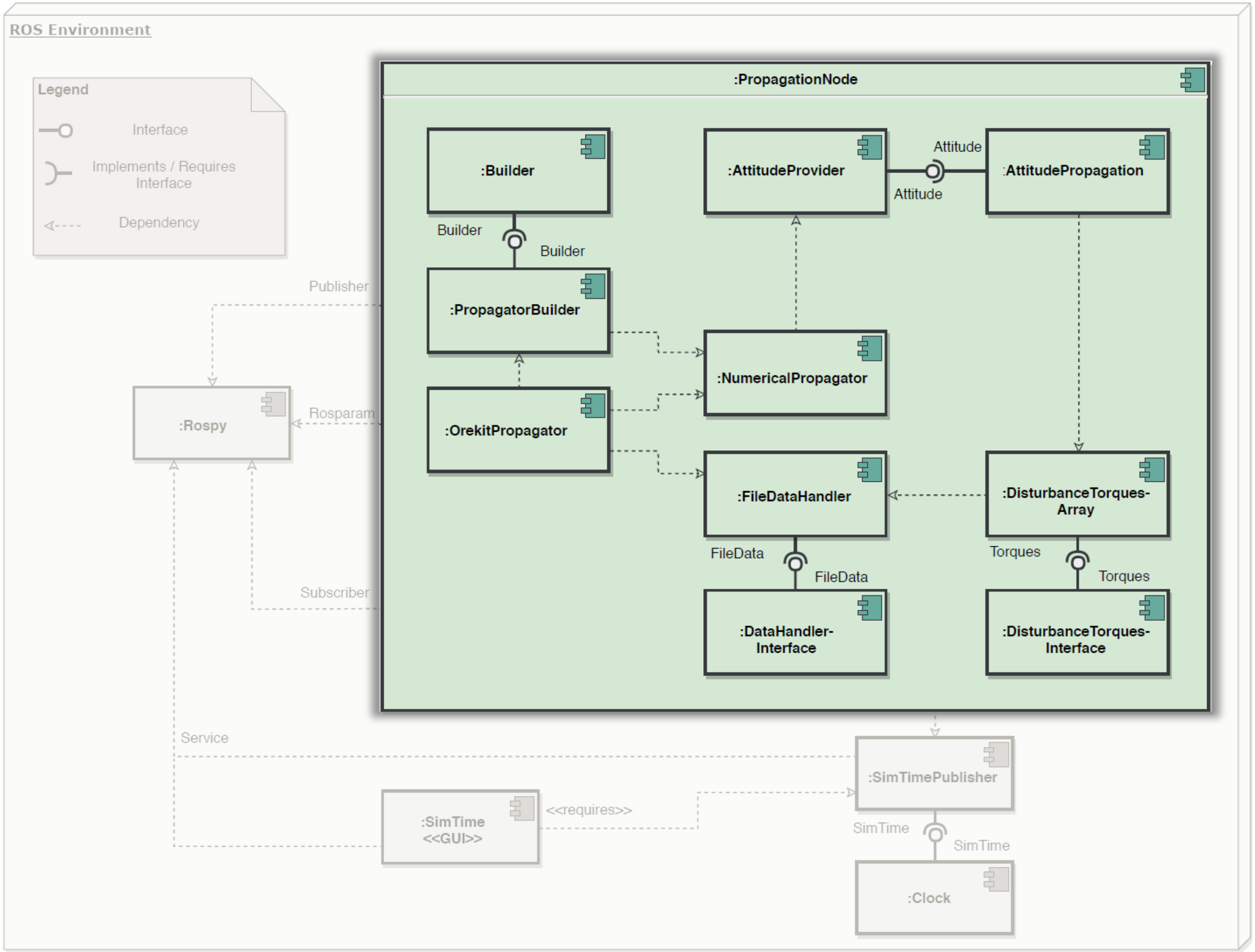


Propa

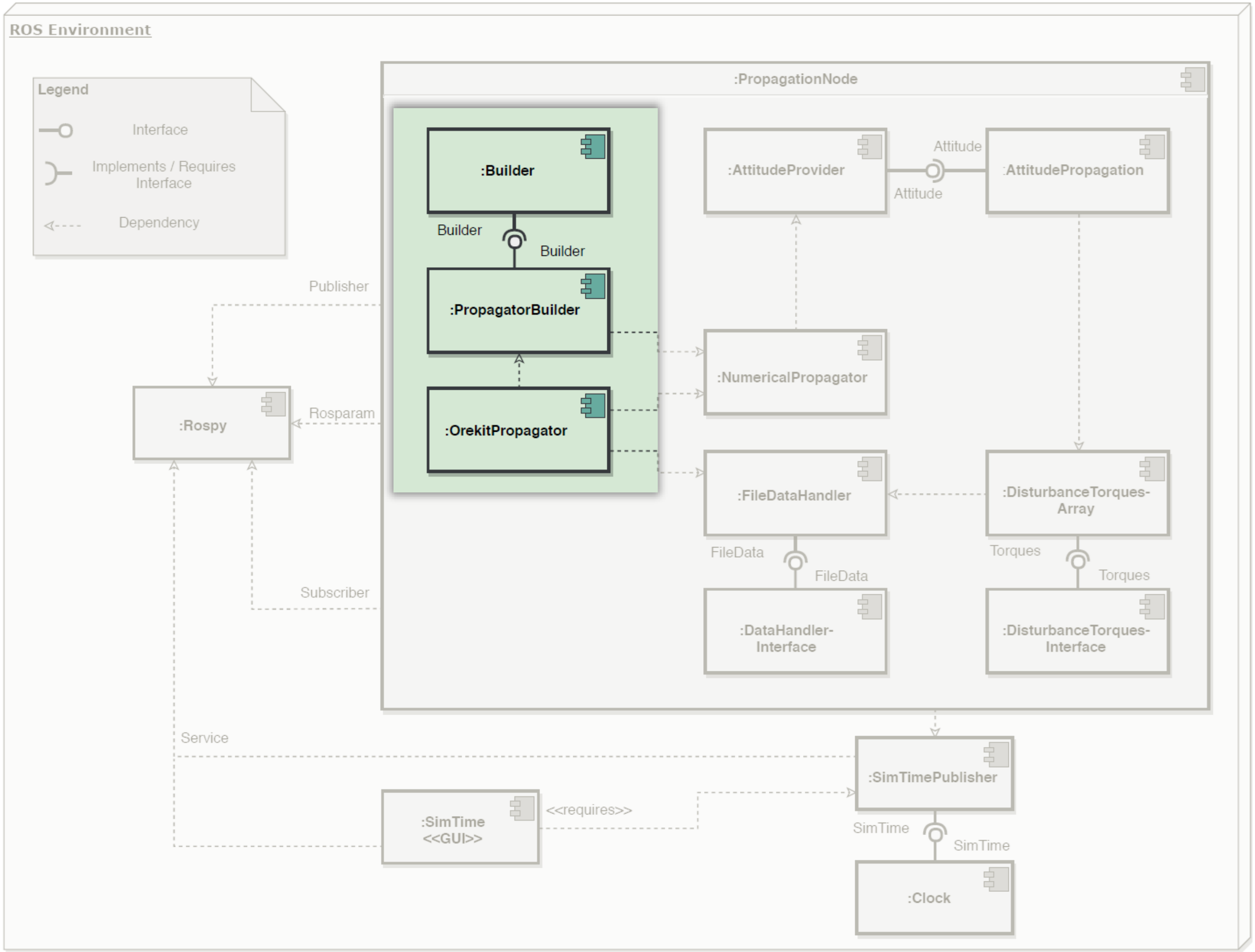


:ROS
:Propagation Node
SimTime : Clock
Publisher : Rospy
Subscriber : Rospy
Chaser : OrekitPropagator
Target : OrekitPropagator
:FileDataHandler
<<create>>
<<create>>
set_up_time()
<<create>>
<<create>>
initialize(settings, init_state, init_epoch)
<<build propagator>>
chaser
initialize(settings, init_state, init_epoch)
<<build propagator>>
target
create_data_validity_checklist()
checklist
loop
while not rospy.is_shutdown()
update()
current_epoch
check_data_availability(current_epoch)
propagate(current_epoch)
get_force_torque()
Force, Torque
chaser_state
propagate(current_epoch)
get_force_torque()
Force, Torque
target_state
publish(chaser_state, target_state)
<<sleep>>
exit()

Propagator Builder

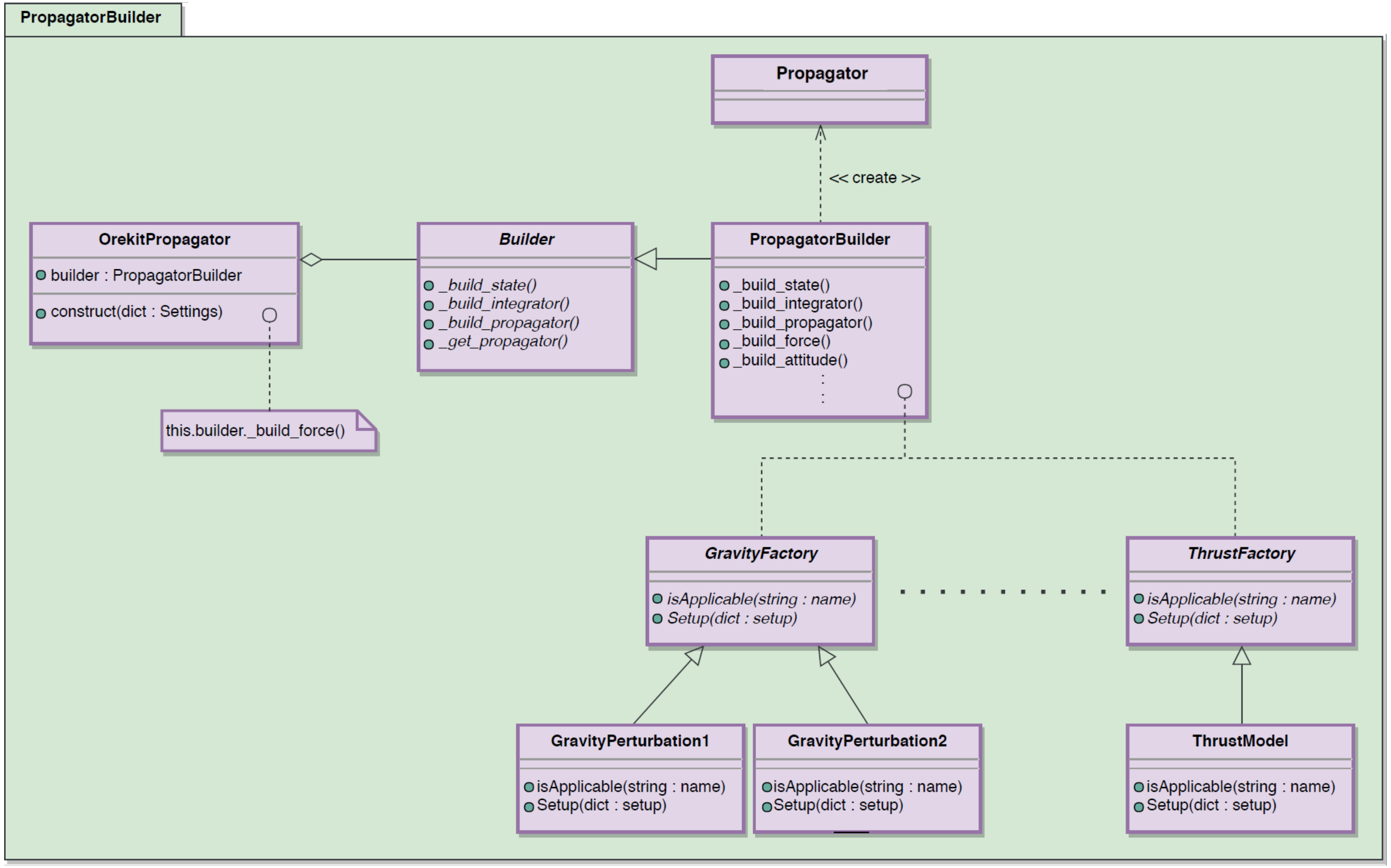


Propagator Builder



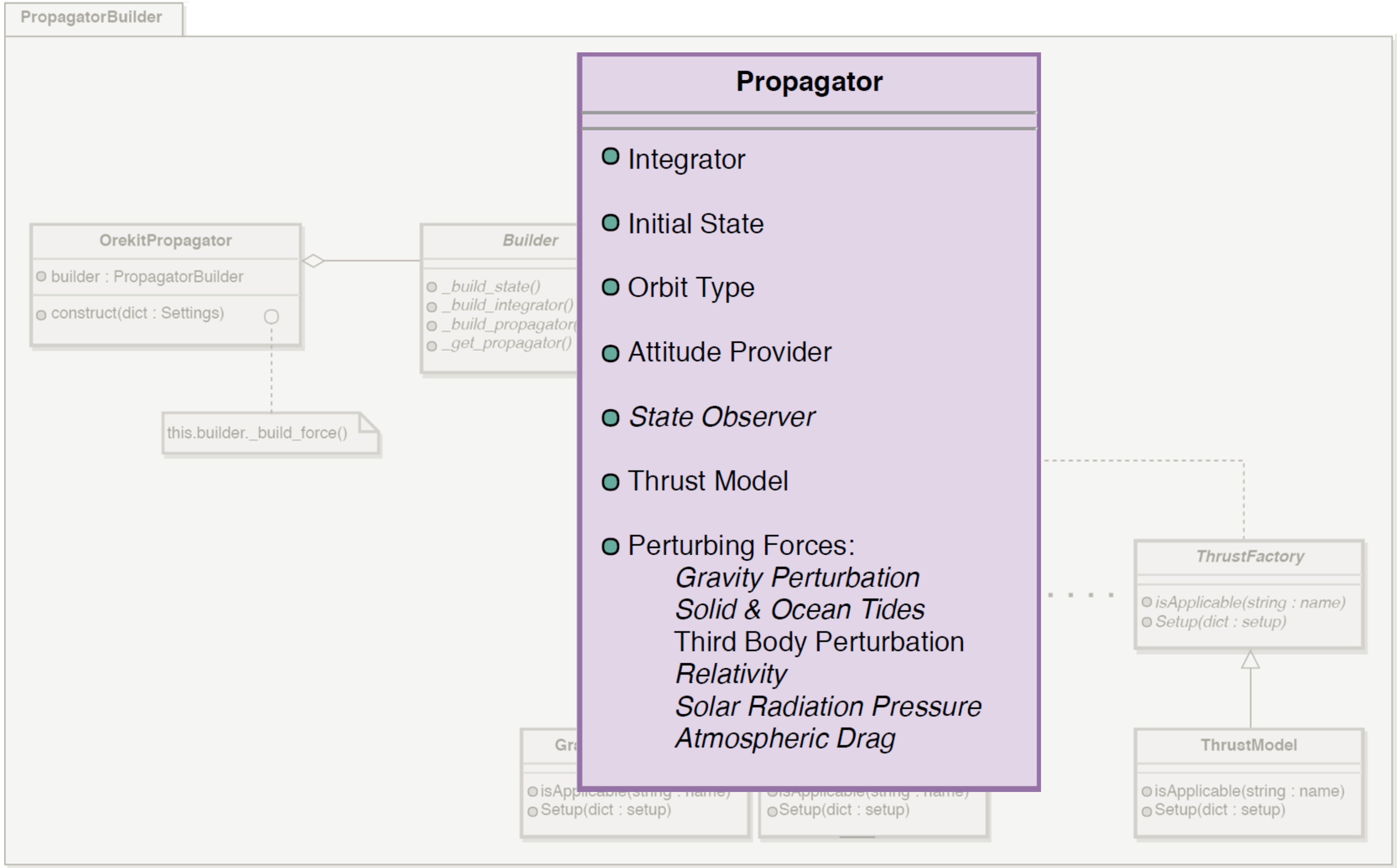
Propagator Builder

- Builder pattern
- .yaml file to define propagator's setup
- Expandable by adding classes inheriting from corresponding factories

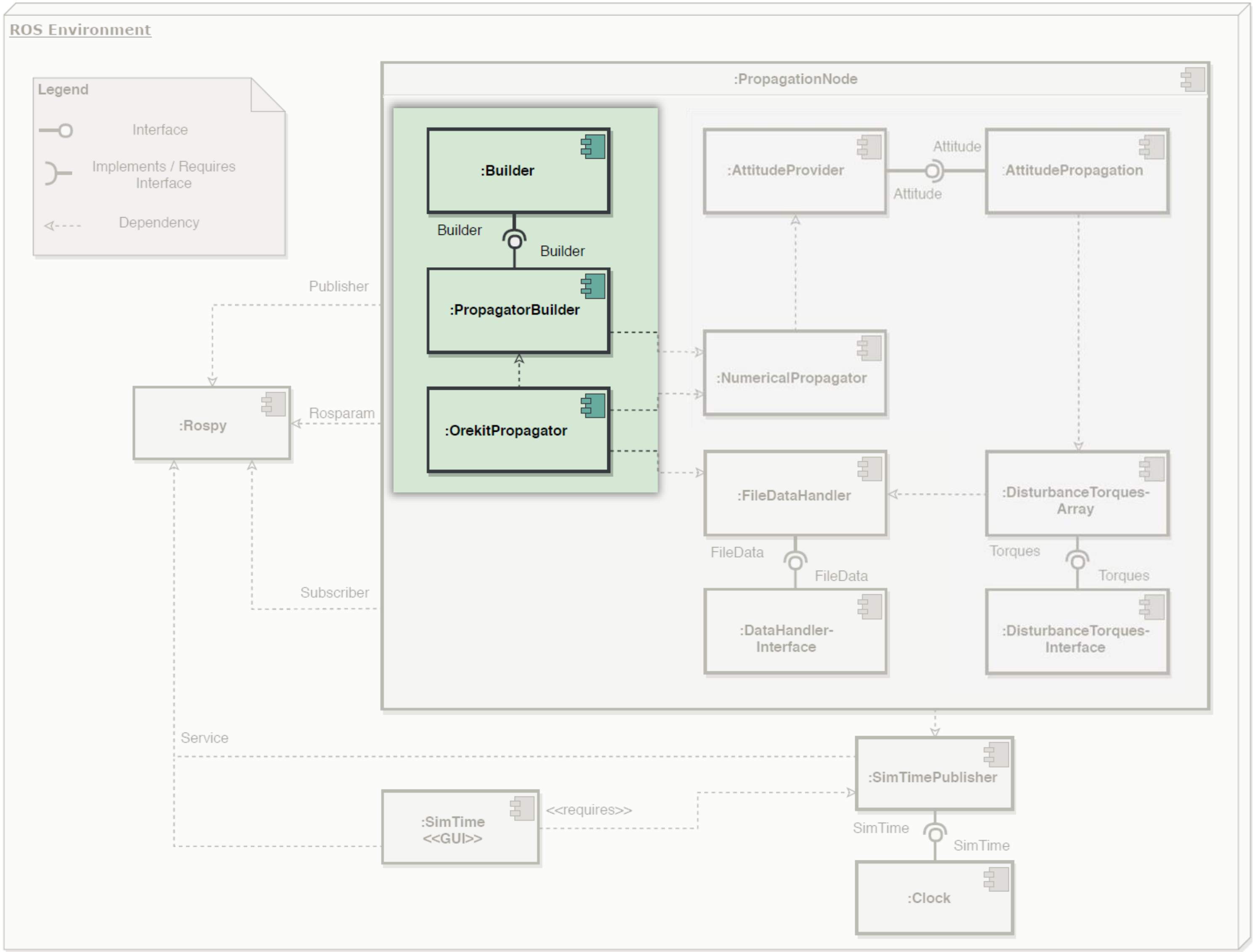


Propagator Builder

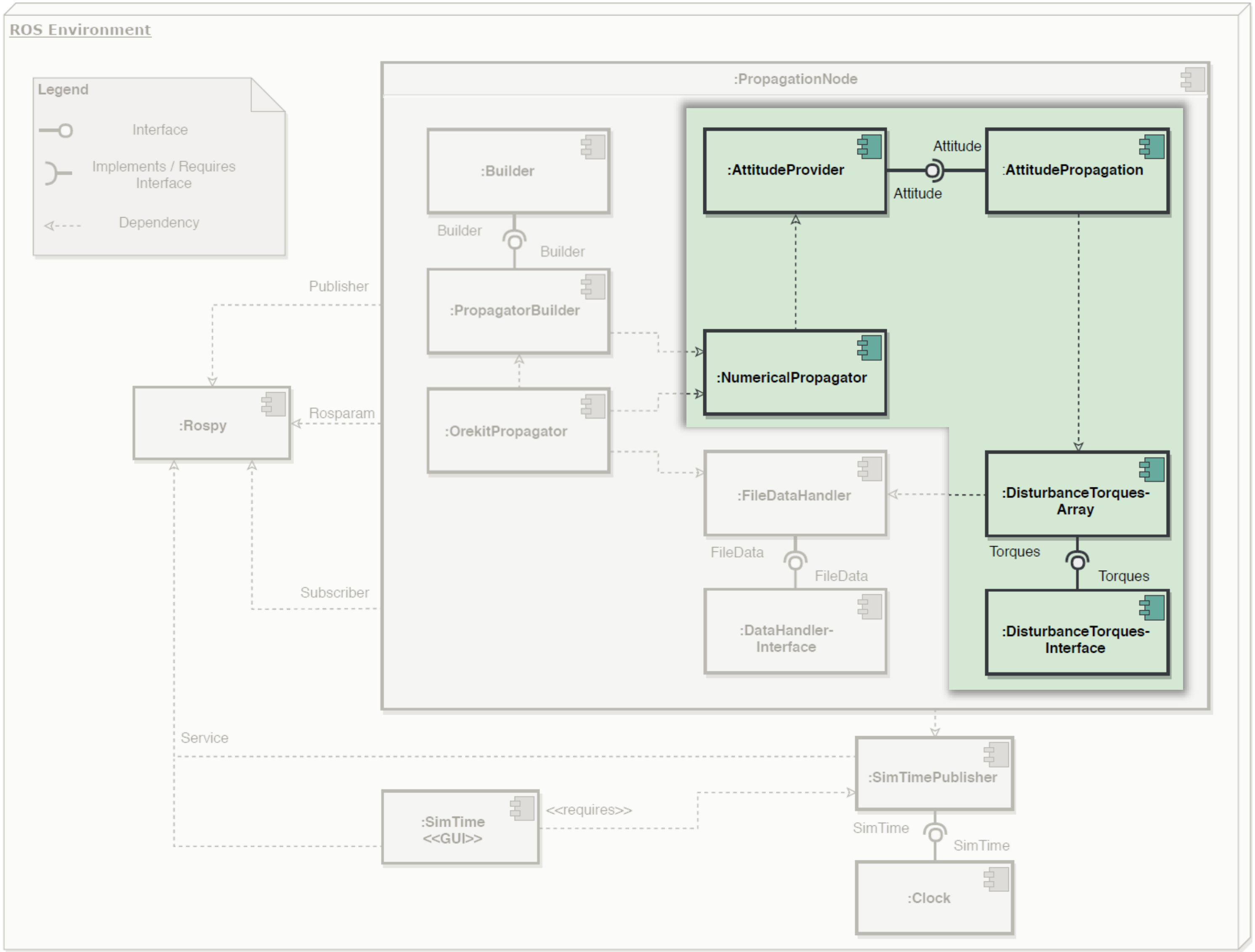
- Builder pattern
- .yaml file to define propagator’s setup
- Expandable by adding classes inheriting from corresponding factories



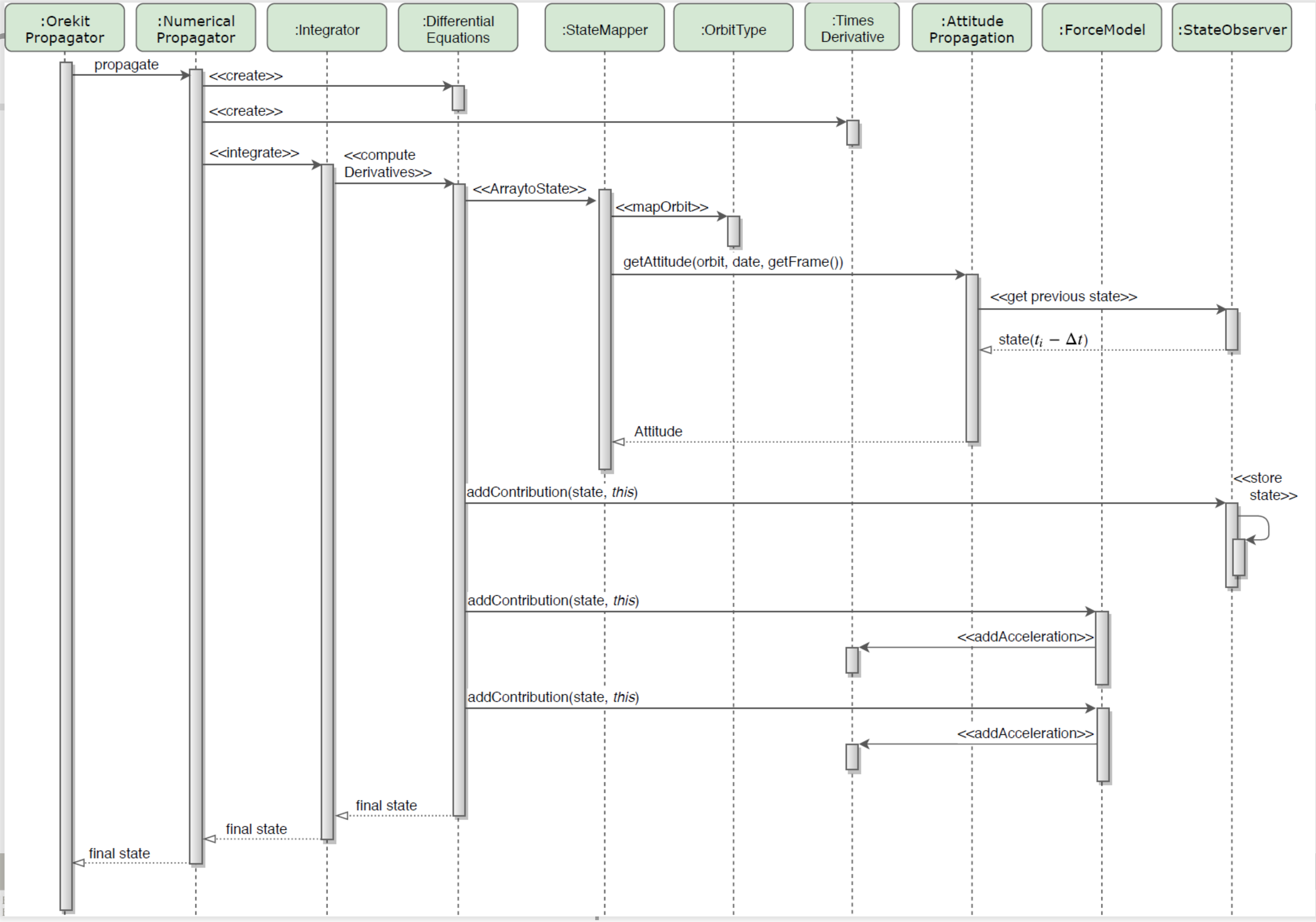
Numerical Propagation



Numerical Propagation

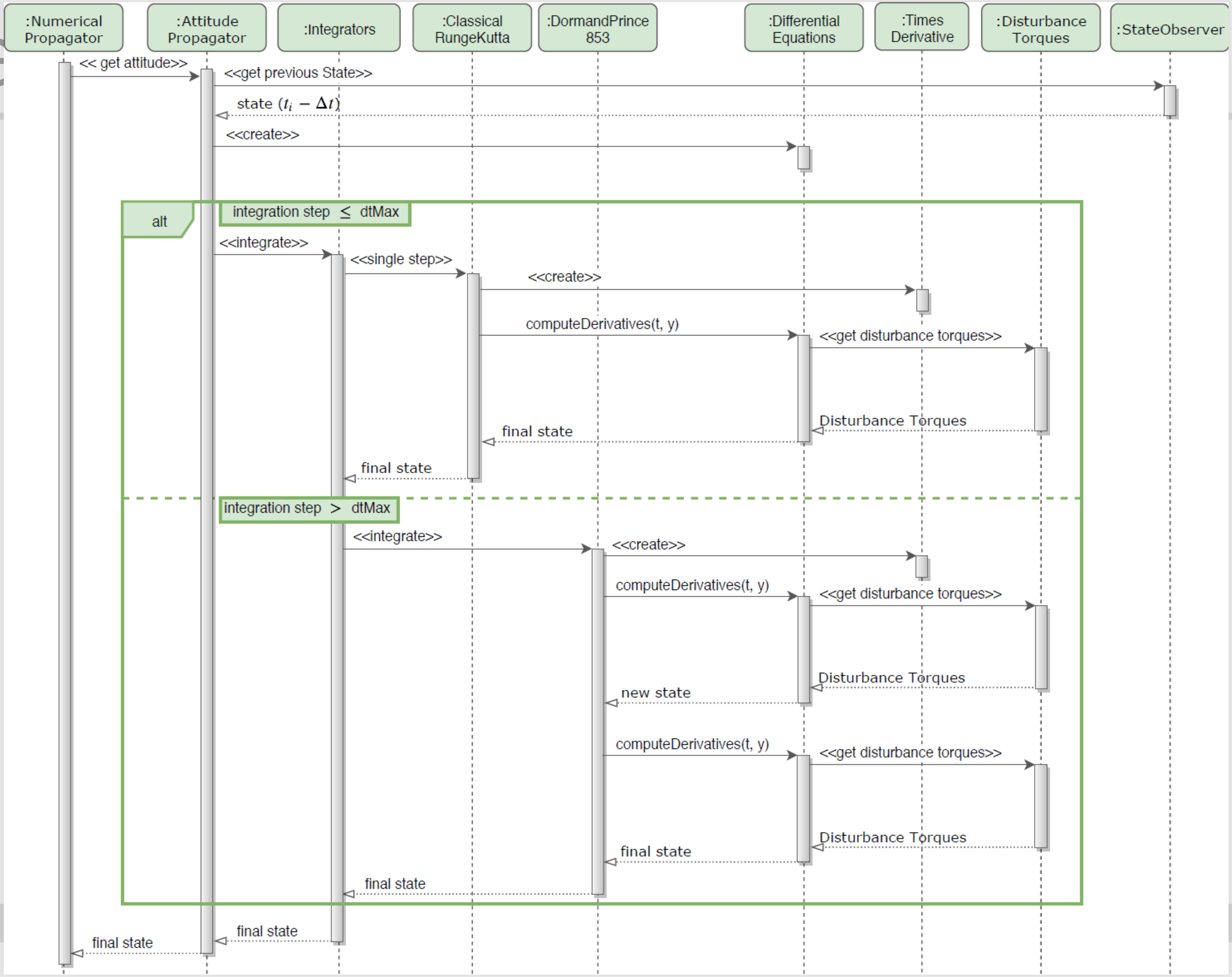


Nur



ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Nume

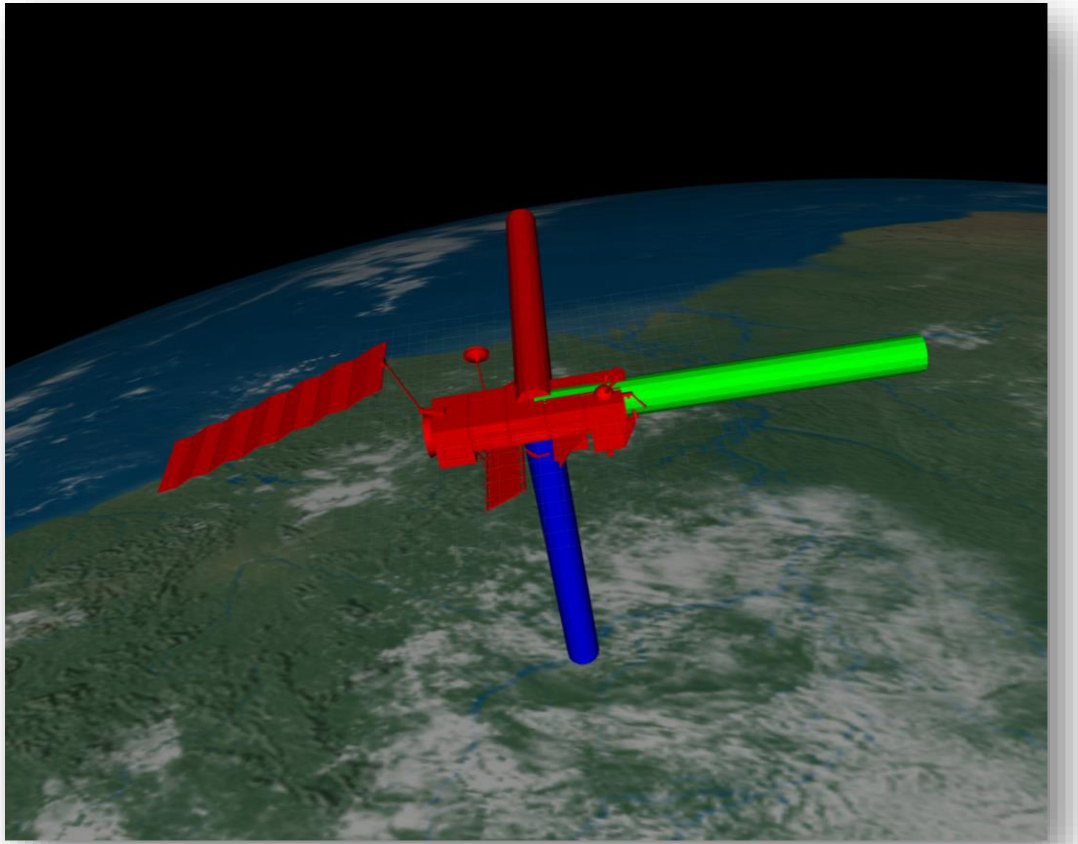


ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Validation of
Orbit Propagation

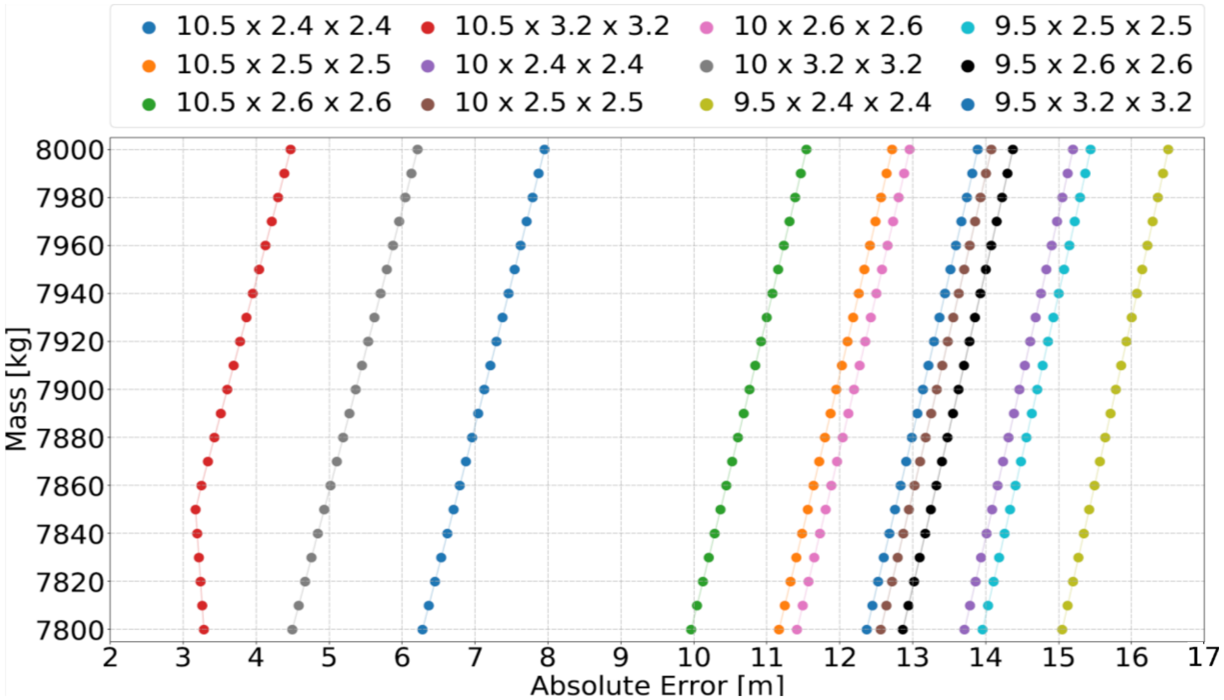
EnviSat Model

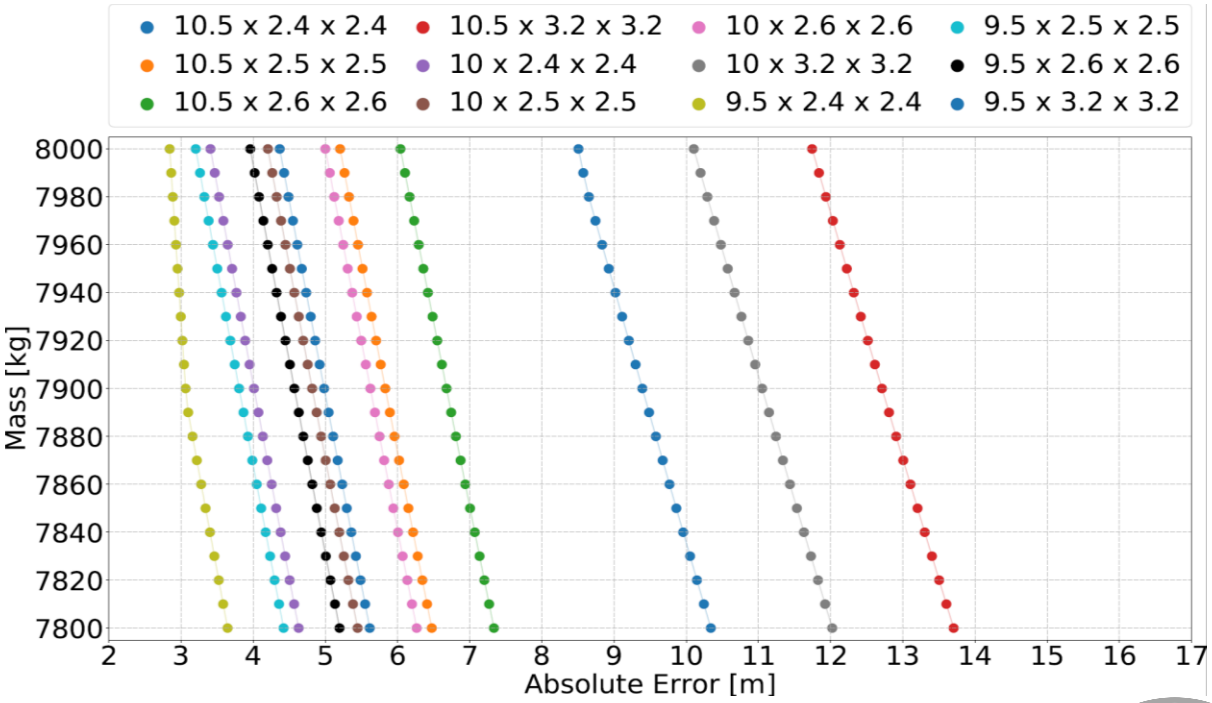
- Simulation results compared against precise orbit data sets of EnviSat for February 2012
- Mass: 7834 kg
- Perfectly nadir pointing attitude assumed
- Solar Panel oriented in direction of best lighting conditions
- Shadowing effect neglected
- Assumptions made for surface material
- Body size ⟶ Sensitivity Analysis



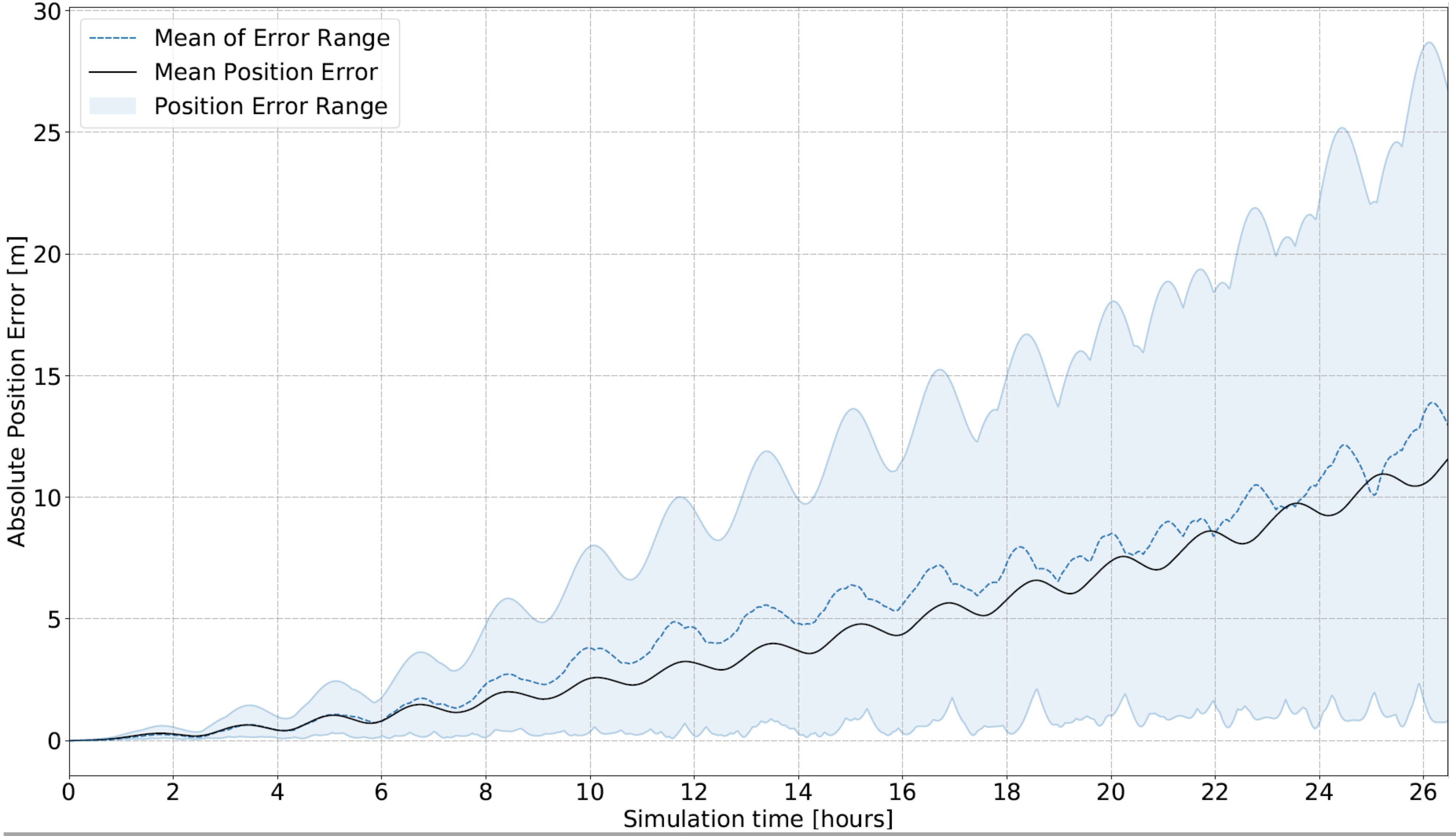
Sensitivity Analysis

- 12 different sizes for masses between 7800 – 8000 kg with 10kg increment
- Solar panel areas: 40 m² *(left)* and 60 m² *(right)*
- Period: *04.02.2012 at 21:55:26 – 06.02.2012 at 00:23:25*

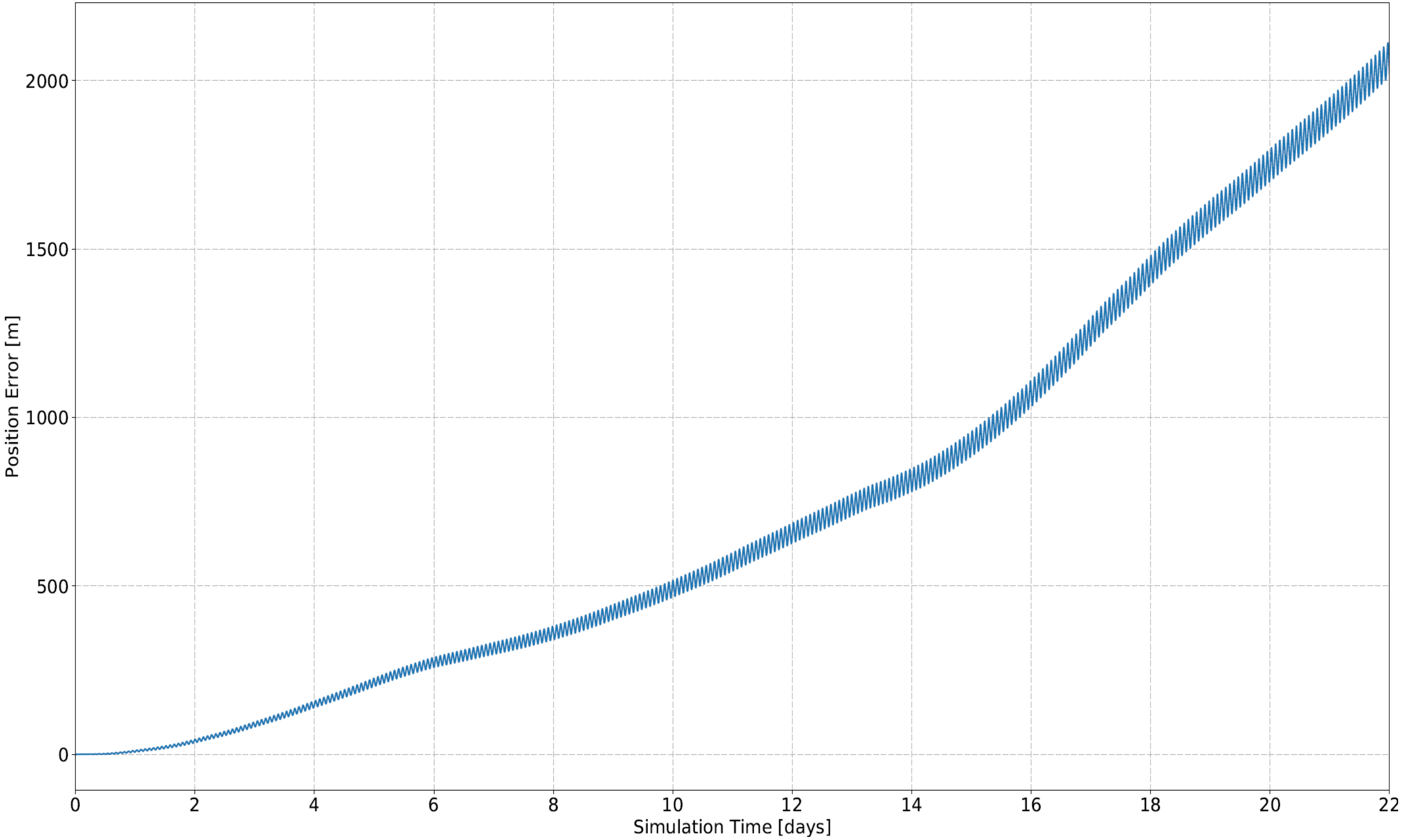




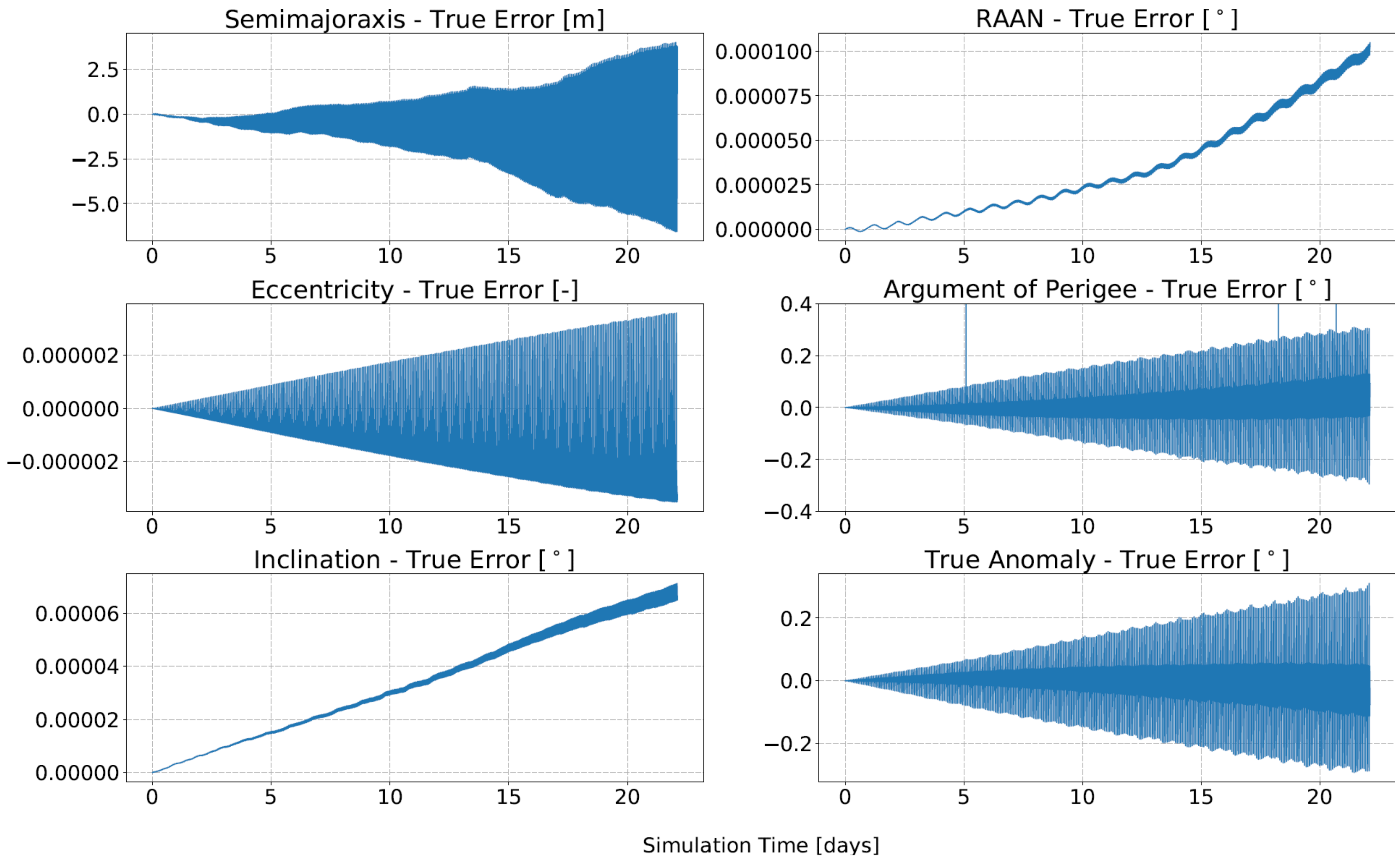
Short-Term Propagation



Long-Term Propagation



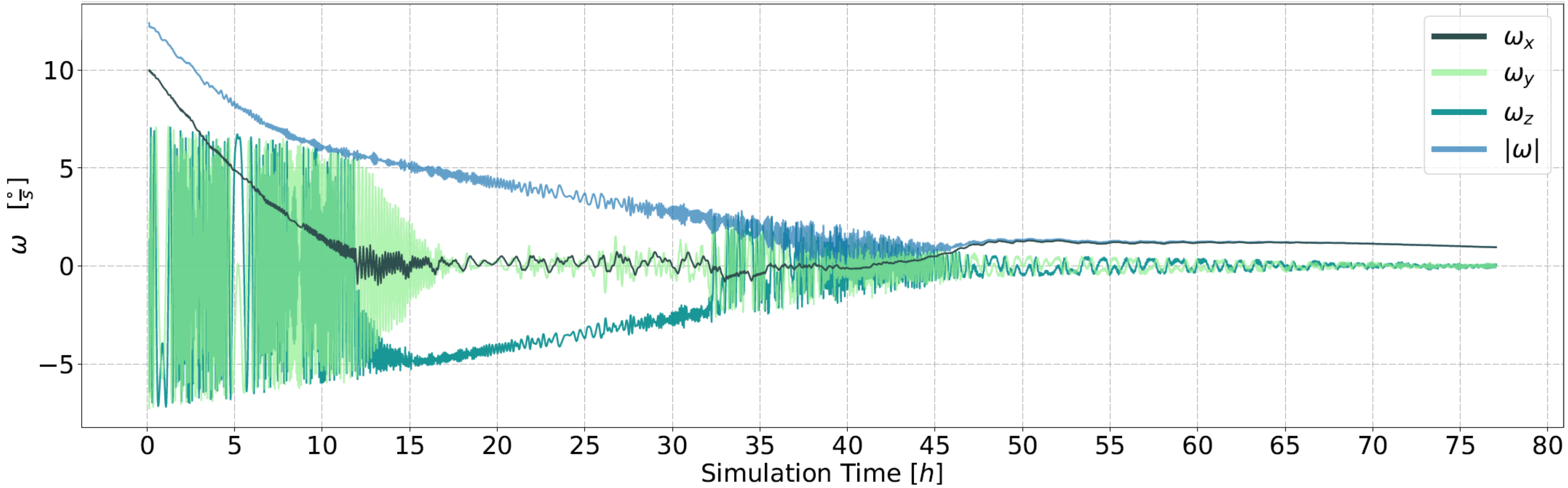
Long-Term Propagation



Validation of Attitude Propagation

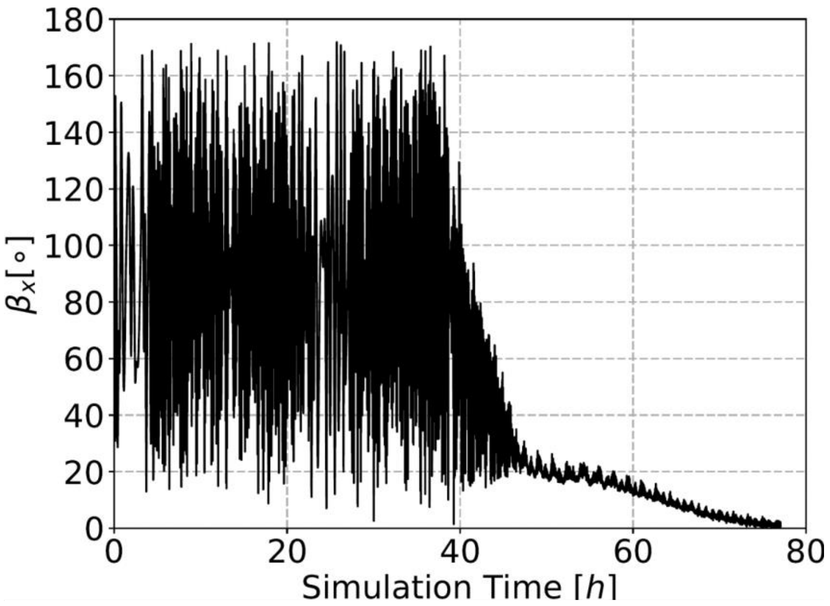
Attitude Propagation

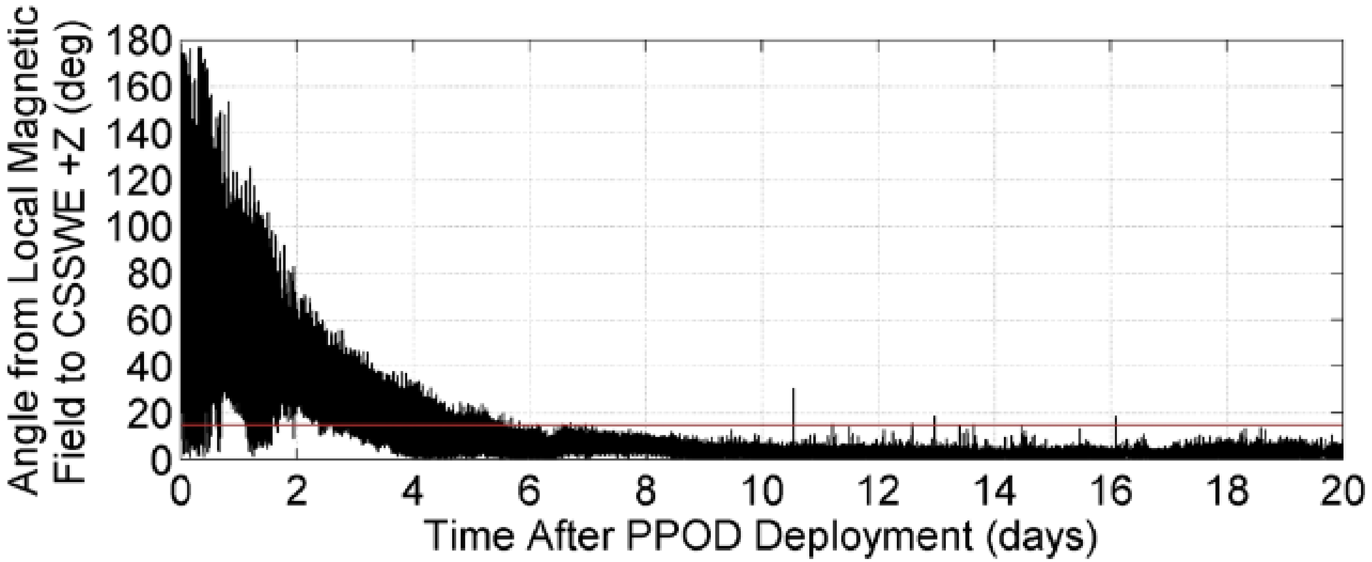
- CSSWE – Passive Magnetic Attitude Control
- 3U CubeSat with mass of 3 kg
- Initial angular velocity: $(\omega_x, \omega_y, \omega_z) = (10, 5, 5)\left[\frac{\circ}{s}\right]$

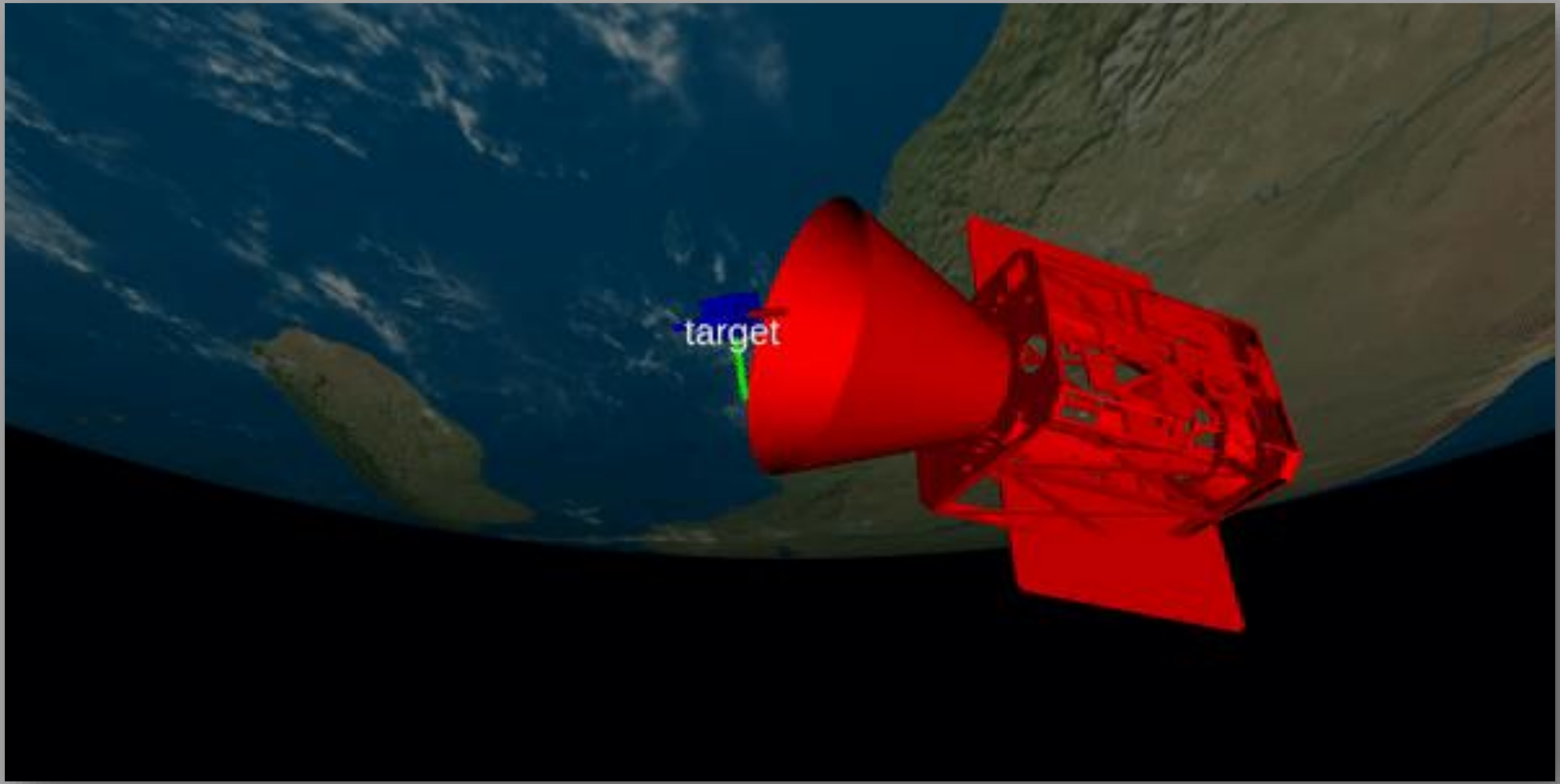


Attitude Propagation

- CSSWE – Passive Magnetic Attitude Control
- 3U CubeSat with mass of 3 kg
- Initial angular velocity: $(\omega_x, \omega_y, \omega_z) = (10, 5, 5)\left[\frac{\circ}{s}\right]$






target

Additional Slides

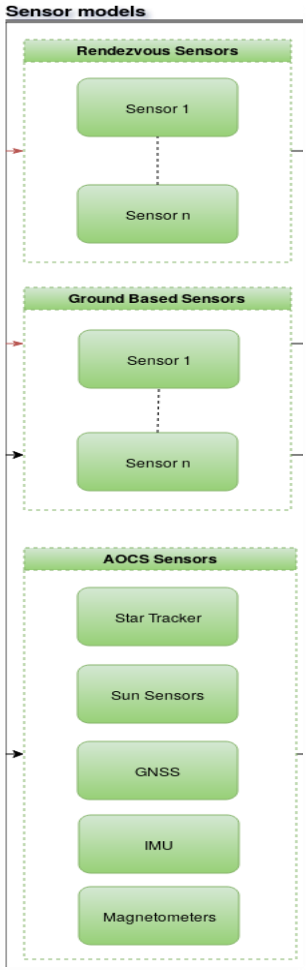
Active Debris Removal

- More than 23‘000 debris larger than 5 cm orbiting Earth
- Even without adding objects to space environment number of debris would grow due to collisions → *Kessler Syndrome*
- Adopted “Post Mission Disposal” (PMD) guidelines do not prevent completely debris increase

  → Active debris removal required

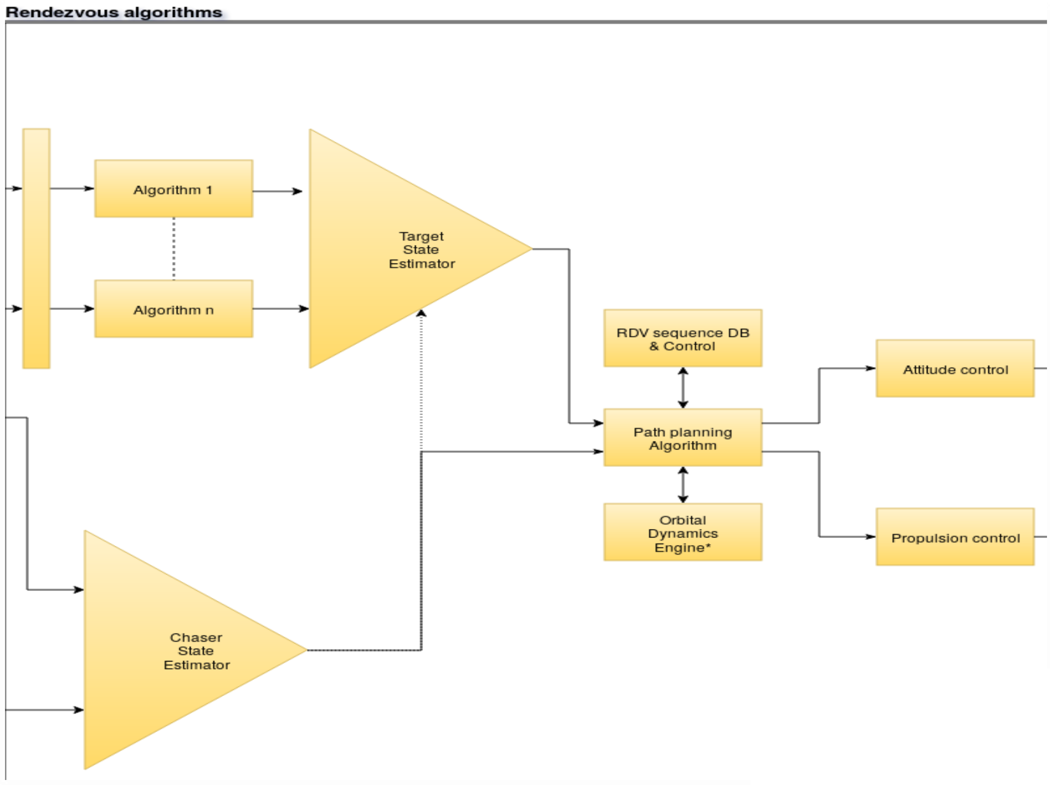
ROSpace – Simulation Framework

- Augments on-board and on-ground sensor readings
- Implemented: **Black box model**
  → returns bearing angles based on relative position and adds artificial noise



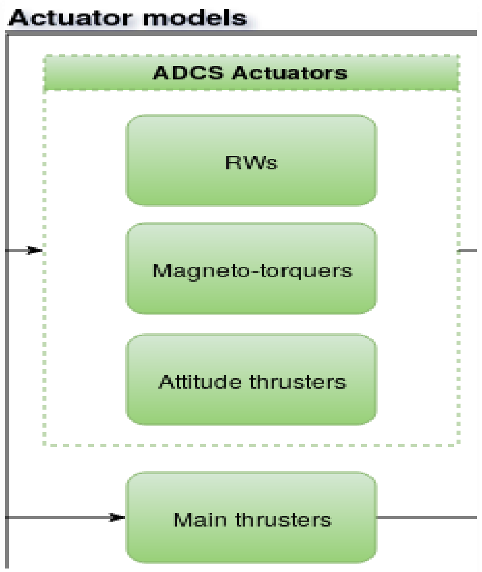
ROSpace – Simulation Framework

- Represents all on-board software
- Implemented: **Relative navigation filter**
  → estimates the relative state of chaser based on inputs from relative navigation sensors and on-board state estimation



ROSpace – Simulation Framework

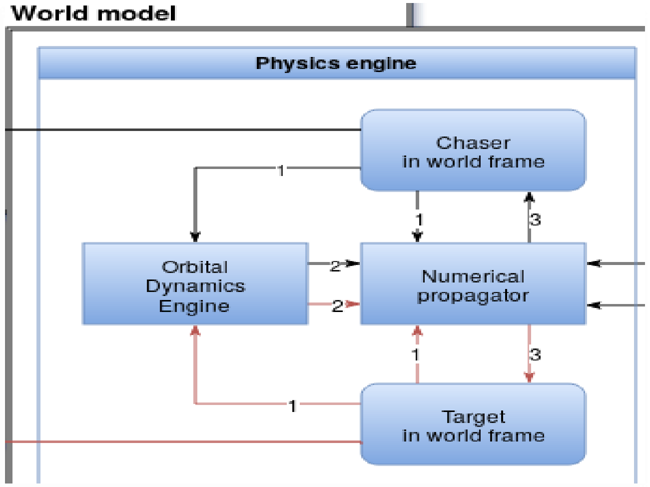
- Models resulting thrust forces based on flight software commands
- Implements: **magneto-torque** & **simple dipole model**



ROSpace – Simulation Framework

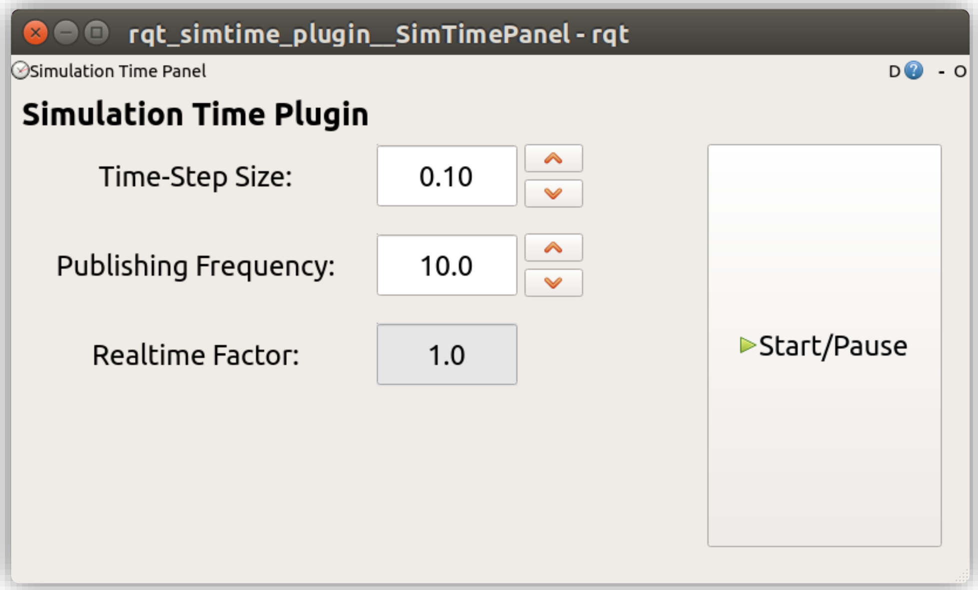
- Models forces and torques acting on the spacecraft and integrates its state (position, velocity, attitude, …)

  ⟶ **Physics engine**



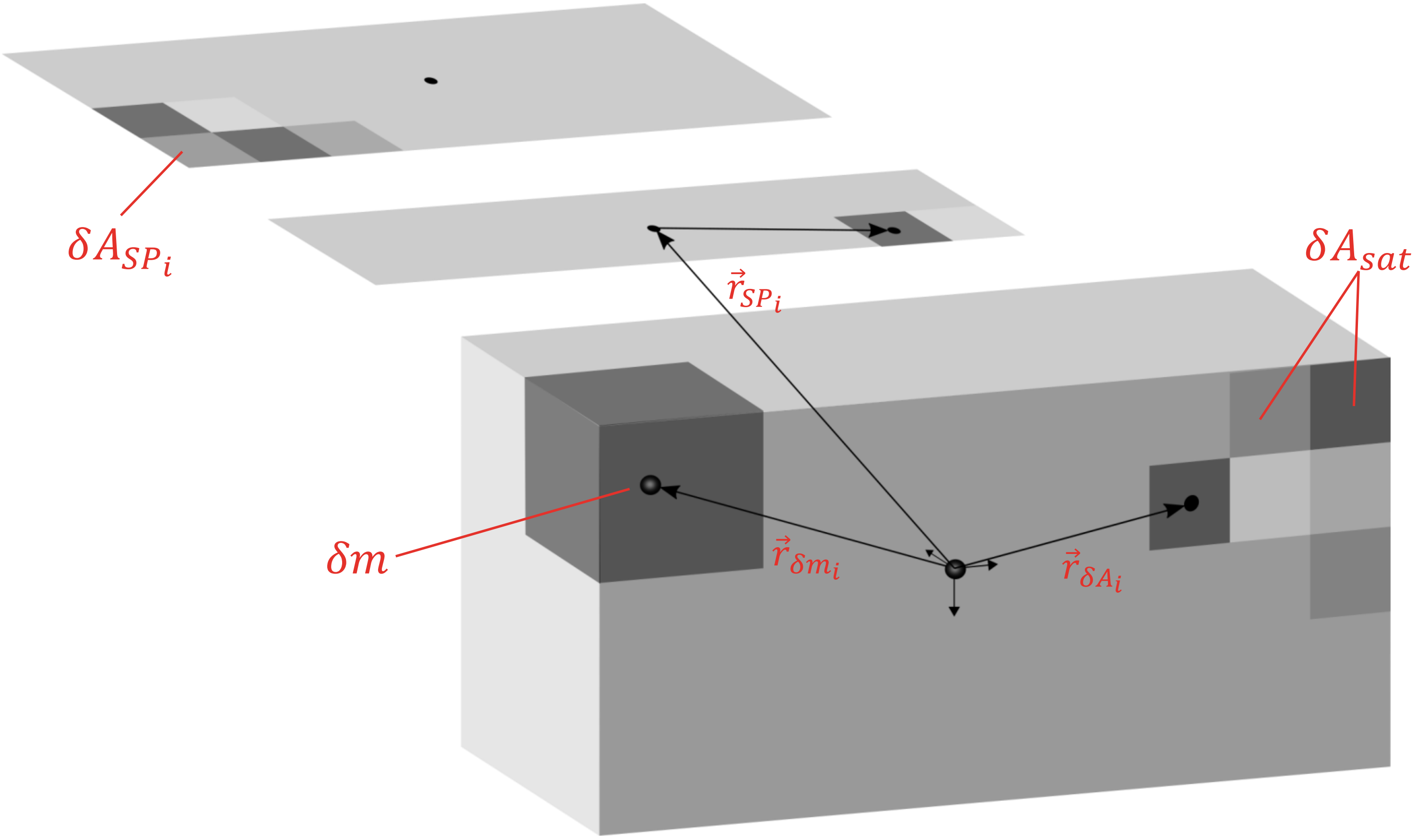
Simulation Time

- Propagator node updates simulation time
- Simulation time represented as integer in [ns]
  $\longrightarrow$ no floating point error
  $\longrightarrow$ python integer $\longrightarrow$ ’long’ integer object
- $TStepSize * PublishFreq = RealTFactor$
- Start/Pause: starts/stops only simulation time update not ROS nodes
- Simulation warns if real-time factor cannot be achieved



Box-Wing Model

- Satellite modeled as box with wings as solar panels
- Discretized into n volumes with mass δm
- Surface discretized into m surfaces with area δA
- Solar Panels 2D planes with fixed direction
- No shadowing effect implemented

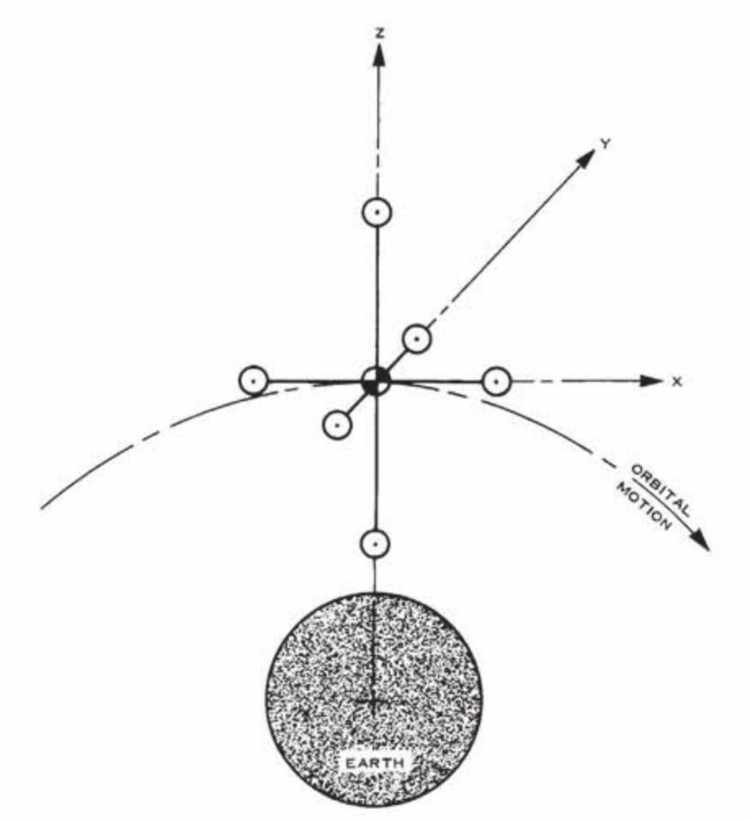


Attitude Propagation

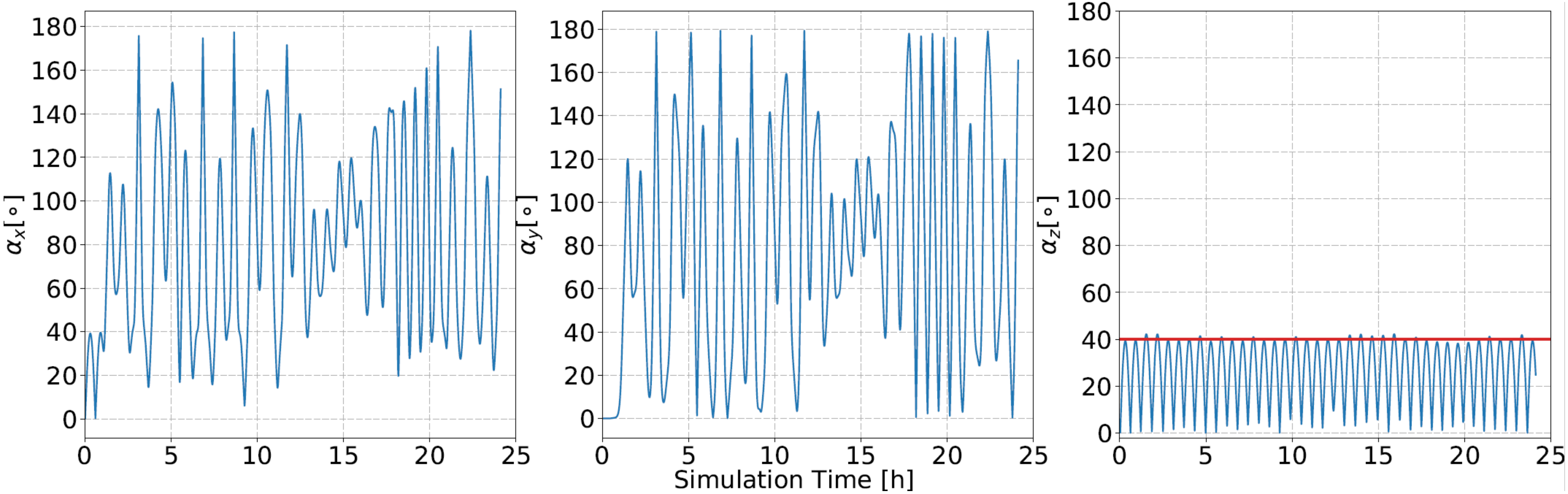
- Gravity Gradient Stabilization inspired by NASA‘s Transit Satellites

- 6 booms with point masses of 1.4 kg at end

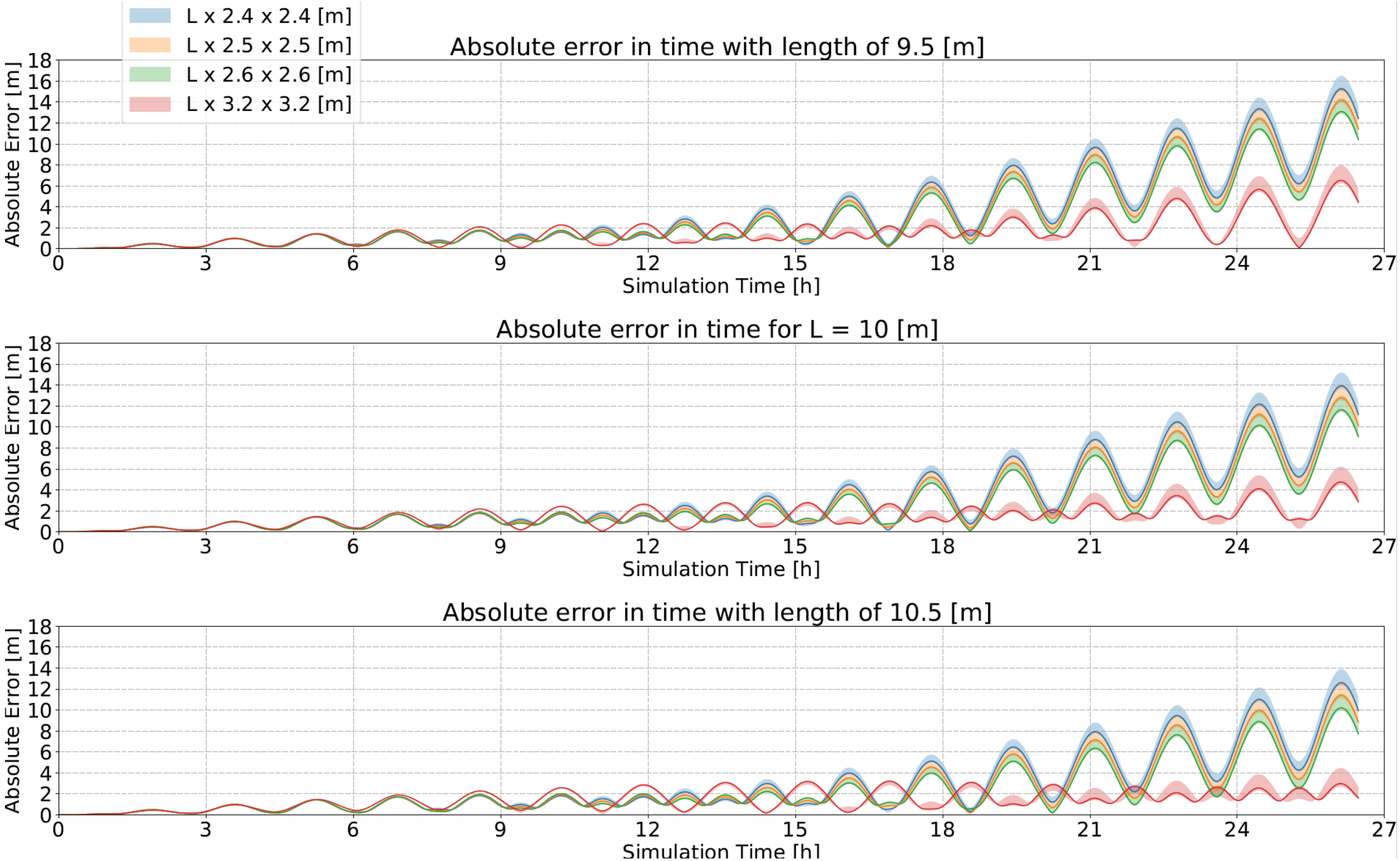
- Inertia tensor is diagonal matrix with $I_x = I_y \gg I_z$



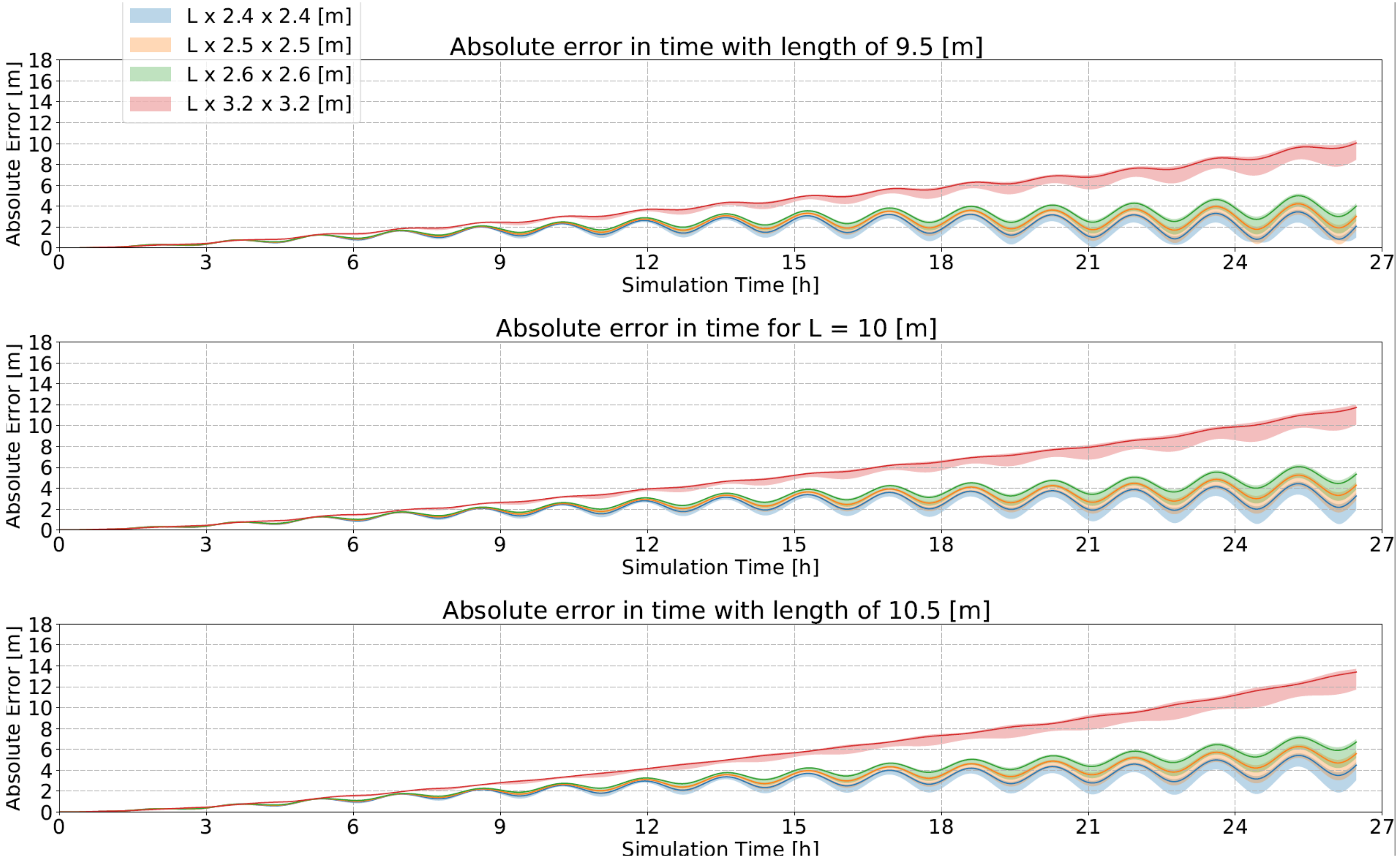
Attitude Propagation



EnviSat – Absolute Error for $40m^2$



EnviSat – Absolute Error for 60m²

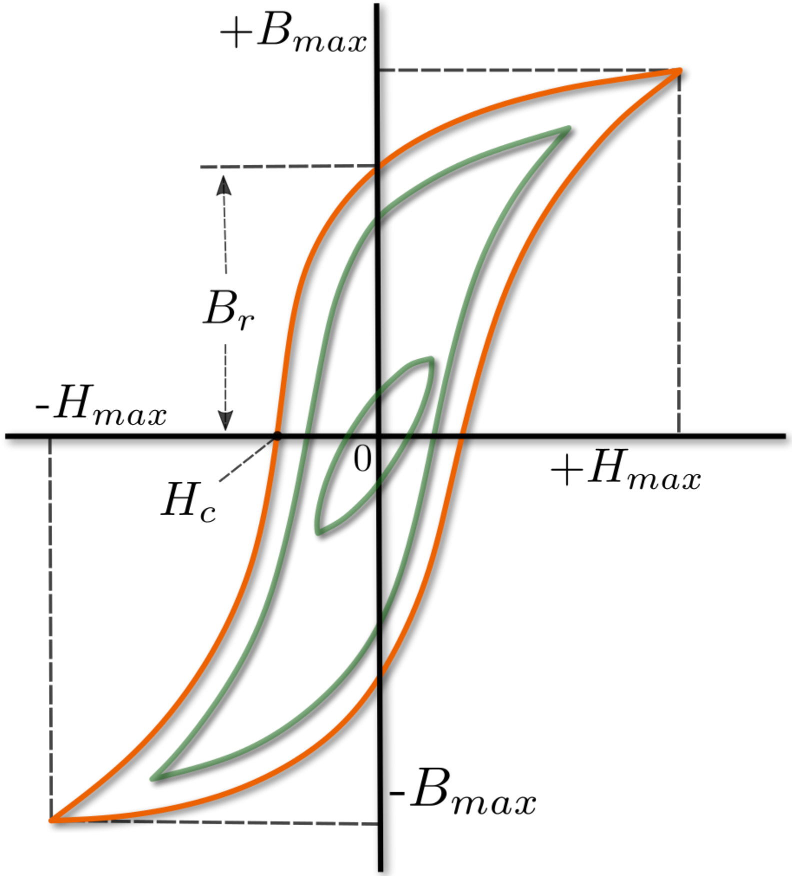


Dipole Model

- One hysteresis loop assumed for every field strength cycle
- Real hysteresis rod follows different loop
- H_c ⟶ Coercive Force

  B_r ⟶ Remanence

  B_s ⟶ Saturation Induction



Provided File Data

Model	Data File Name	Format	Provider
Gravity Field	eigen-6s.gfc	ICGEM format	International Centre for Global Earth Models [38]
	egm96_to360.ascii	EGM format	NASA's Goddard Space Flight Center [39]
Ocean tides	fes2004_Cnm-Snm.dat	FES format	Aviso (with support from CNES) [40]
Atmosphere	Sep2017F10.txt	MSAFE format	NASA's Marshall Space Flight Center [41]
	sw19571001.txt	Celestrak format	CelesTrak [42]
Magnetic field	WMM15.COF	WMM format	National Centers for Environmental Information [43]
	IGRF12.COF	IGRF format	International Association of Geomagnetism and Aeronomy [44]
Date conversion	tai-utc.dat	USNO tai-utc	United States Naval Observatory [45]
Earth Orientation Parameters (EOP)	finals.all	IERS standard EOP	(all three provided by)
	finals2000A.all	IERS standard EOP	International Earth Rotation and Reference Systems Service [46]
	eopc04_08_IAU2000.03	IERS EOP 08 C04	
Ephemerides	lnxp1990.430	DE 4xx binary	NASA's Jet Propulsion Laboratory [47]