NEURAL INFORMATION PROCESSING SYSTEMS

PRR Plano de Recuperação e Resiliência

REPÚBLICA PORTUGUESA

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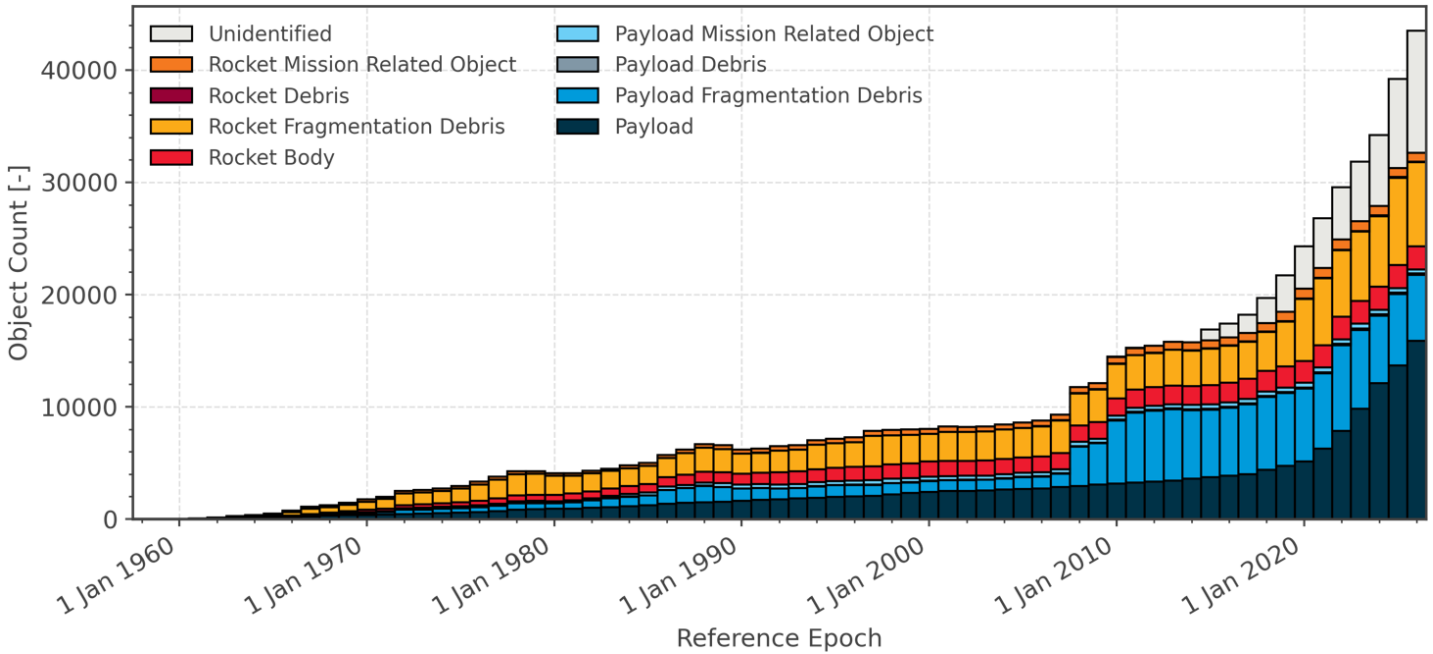
NOVA SCHOOL OF SCIENCE & TECHNOLOGY

OrbitZoo: Real Orbital Systems Challenges for Reinforcement Learning

Alexandre Oliveira, Katarina Dyreby, Francisco Caldas, Cláudia Soares

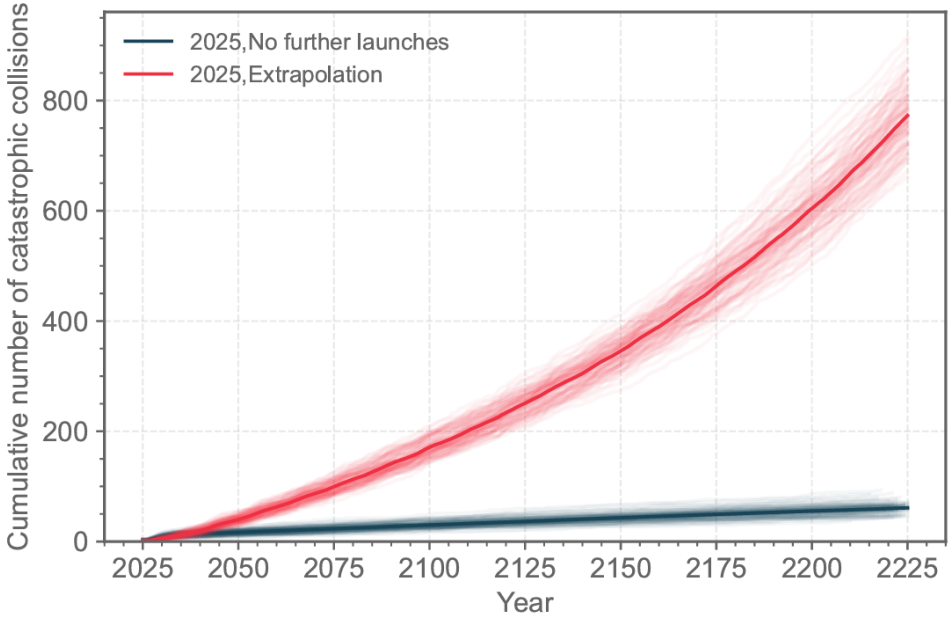
Orbital Environment



Evolution of number of objects in geocentric orbit by object class.

Source: European Space Agency - Space Environment Report 2025 (www.sdo.esoc.esa.int/publications/Space_Environment_Report_I9R1_20251021.pdf)

Orbital Environment



Number of cumulative collisions in LEO in simulated scenarios of long-term evolution of the environment.

Source: European Space Agency - Space Environment Report 2025 (www.sdo.esoc.esa.int/publications/Space_Environment_Report_I9R1_20251021.pdf)

Challenges in RL for Orbital Dynamics

Complex Orbital Dynamics

Propagation

Perturbations

Integration

Challenges in RL for Orbital Dynamics

Complex Orbital Dynamics

Propagation

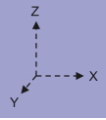
Perturbations

Integration

State Representations

Keplerian

Equinoctial



Cartesian

Challenges in RL for Orbital Dynamics

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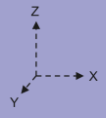
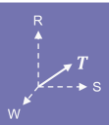


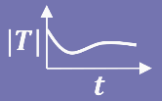
Cartesian

Thrust Control



Representation

Constraints



Realism

Challenges in RL for Orbital Dynamics

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Complex Orbital Dynamics

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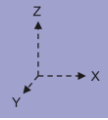
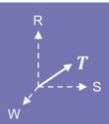
Equinoctial



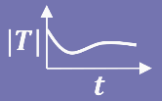
Cartesian

Thrust Control



Representation

Constraints



Realism

Learning and Exploration

Multi-Agent

RL Algorithms

Scalability

Reproducibility

Challenges in RL for Orbital Dynamics

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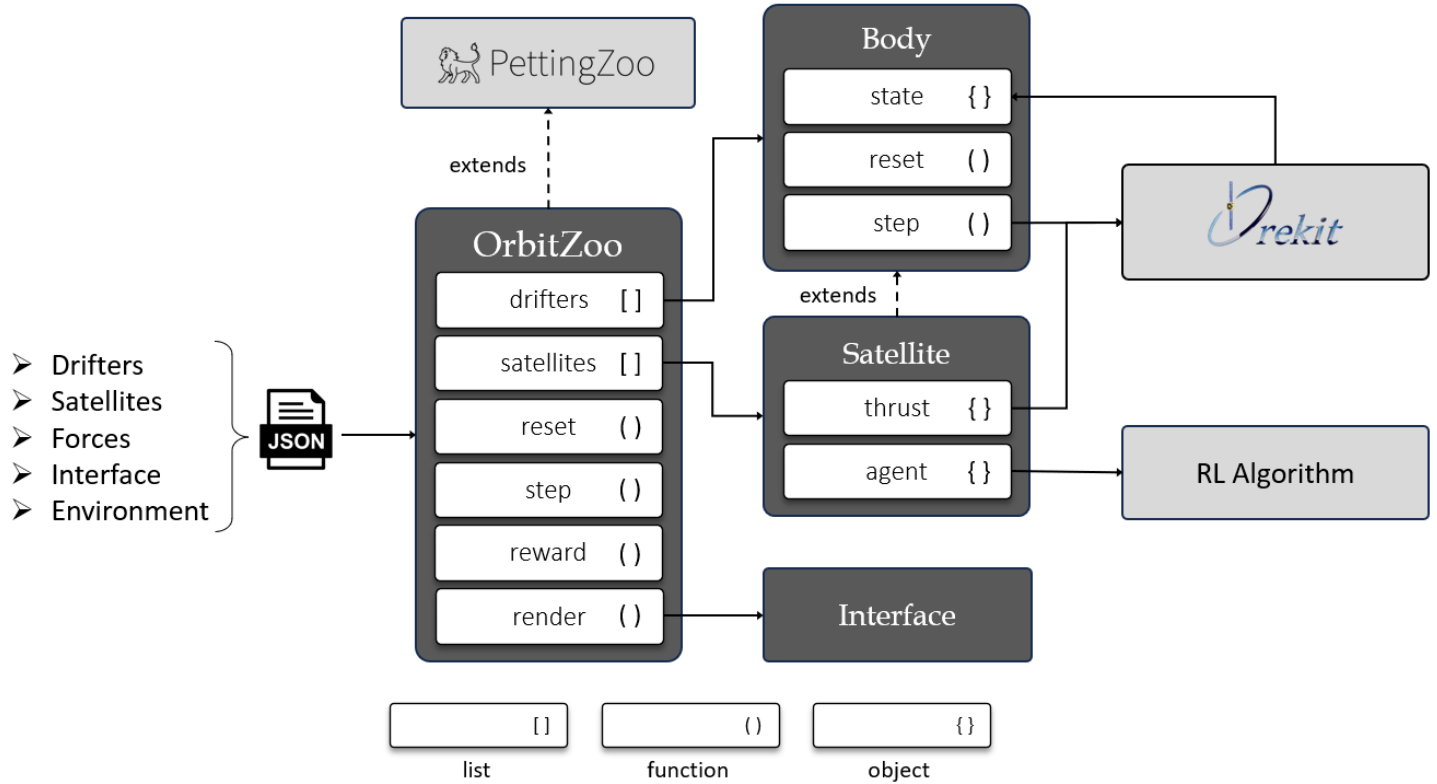
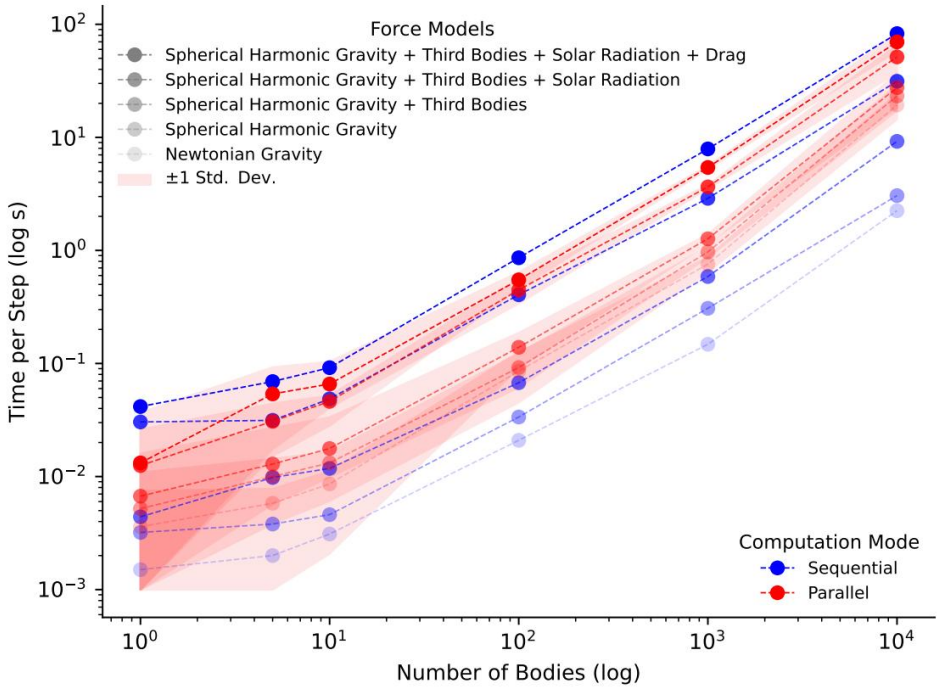
Complex Orbital Dynamics	Propagation	Perturbations	Integration
State Representations	Keplerian	Equinoctial	Cartesian
Thrust Control	Representation	Constraints	Realism
Learning and Exploration	Multi-Agent	RL Algorithms	Scalability
Validation	Ephemeris	Parameter Tuning	Reproducibility

OrbitZoo: Framework

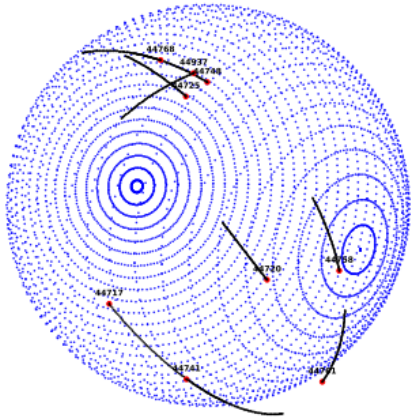


OrbitZoo: Scalability

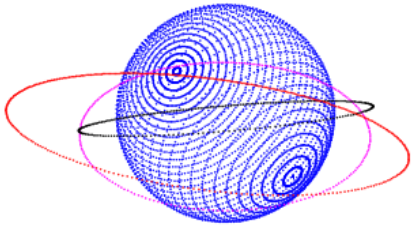


Time per step (in seconds) when using sequential and parallel computations, by the number of bodies and active forces.

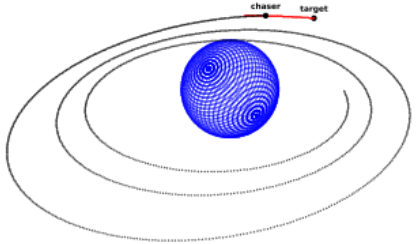
OrbitZoo: Interface



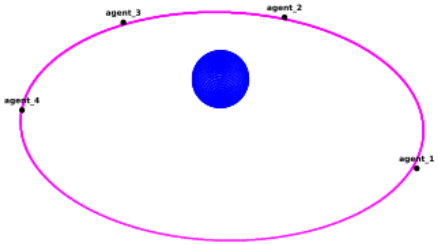
a) A system with a constellation of Starlink satellites.



b) A system with 3 different Keplerian orbits.



c) A single-agent mission: Chase Target.



d) A multi-agent mission: Constellation in GEO.

OrbitZoo: Comparison

Work	Multi-Agent RL	Industry-Standard Simulator	High-Fidelity Dynamics	Continuous Control	Realistic Bodies and Thrust	Interactive Visualization	Publicly Available
Kolosa (2019) [40]		✓		✓	✓		✓
Miller (2019) [49]				✓			
Herrera (2020) [31]			✓(drag only)	✓	✓		✓
Federici (2021) [24]				✓			
Sullivan (2021) [73]				✓	✓		
Casas (2022) [15]		✓	✓	✓	✓		
Bonasera (2022) [12]			✓	✓			
Dolan (2023) [20]	✓		✓(J2 only)	✓	✓		
Bourriez (2023) [13]		✓	✓		✓		
LaFarge (2023) [41]			✓(third bodies only)	✓	✓		
Zhang (2023) [84]	✓	✓		✓			
Qingyu (2023) [60]	✓			✓	✓		
Holder (2024) [34]	✓	✓		✓			
Solomon (2024) [72]		✓	✓	✓	✓		
Kazemi (2024) [38]		✓	✓	✓	✓		
OrbitZoo (ours)	✓	✓	✓	✓	✓	✓	✓

OrbitZoo: Data Validation

Group	Mean RMSE (meters)
Low RMSE	24.14
Medium RMSE	83.75
High RMSE	1924.90

Root mean square error (RMSE), in meters, for three groups of satellites (31 total) based on levels of RMSE.

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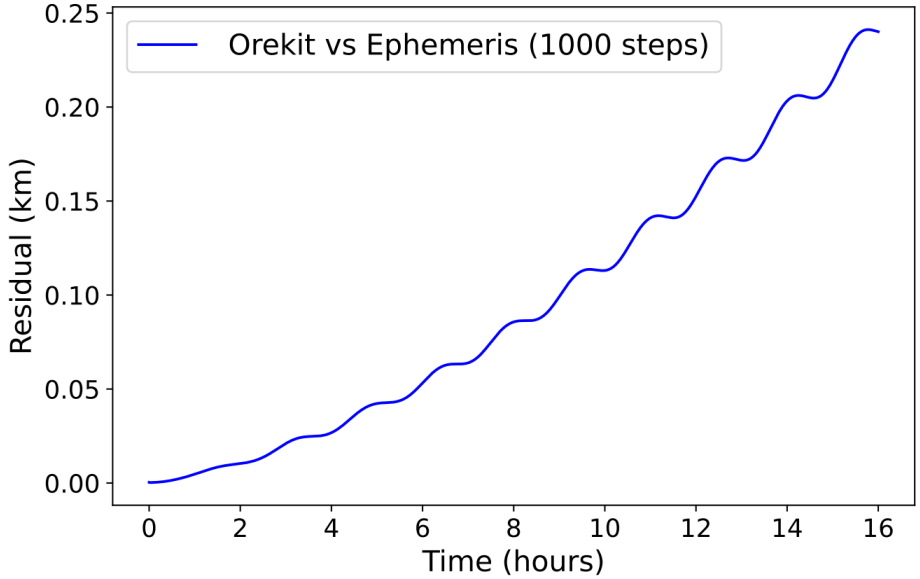
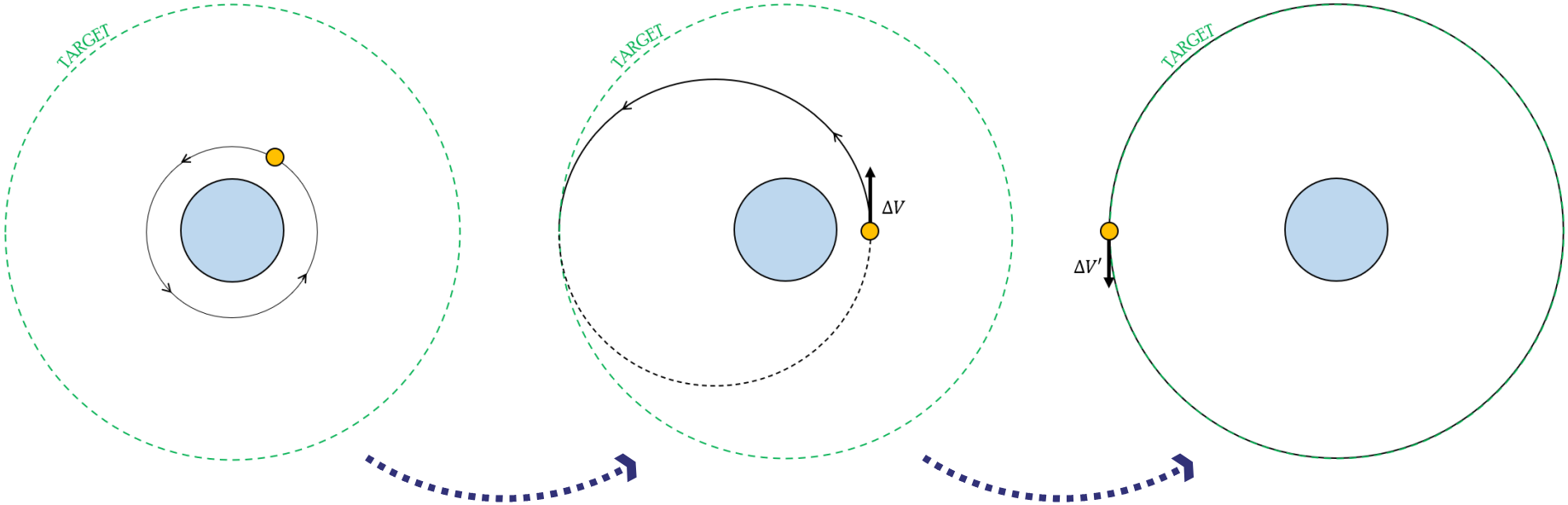


Residuals between OrbitZoo-propagated trajectories and Starlink ephemeris data for satellite 44744.

OrbitZoo: Selected Experiments

Hohmann Manoeuver



OrbitZoo: Selected Experiments

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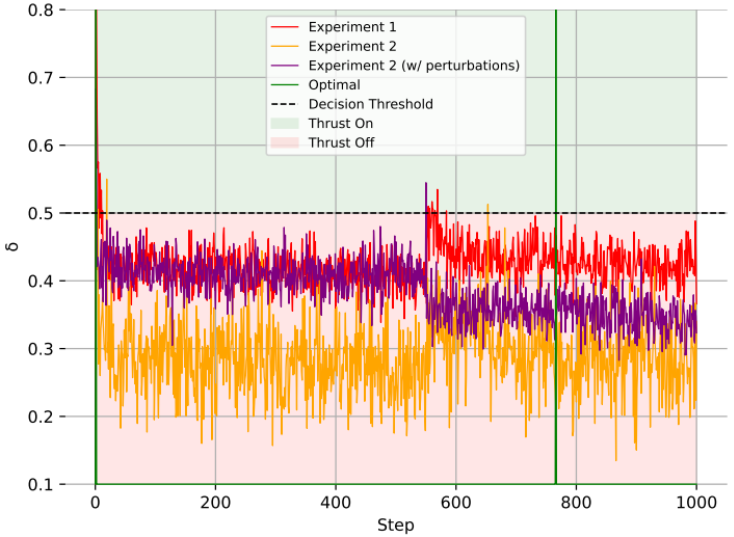
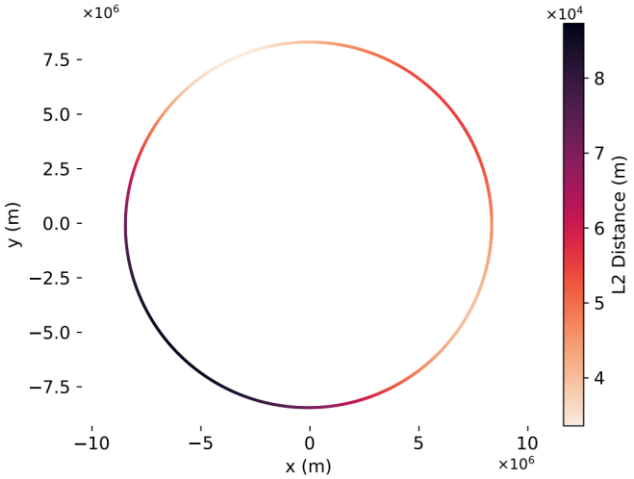


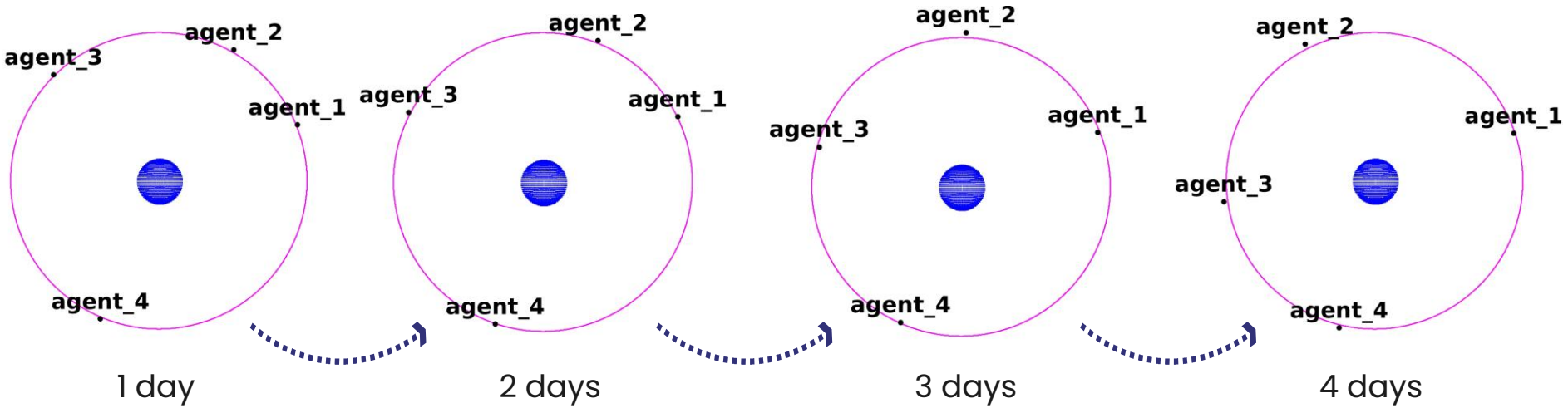
Agents' decisions (δ) to apply thrust during a full episode.



L2 error between the optimal maneuver and Experiment 2 maneuver.

OrbitZoo: Selected Experiments

Multi-Agent Formation



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Thank you!

Alexandre Oliveira	aan.oliveira@campus.fct.unl.pt
Katarina Dyreby	k.dyreby@campus.fct.unl.pt
Francisco Caldas	f.caldas@campus.fct.unl.pt
Cláudia Soares	cam.soares@fct.unl.pt

Trustworthy ML Research Group @ NOVA School of Science and Technology